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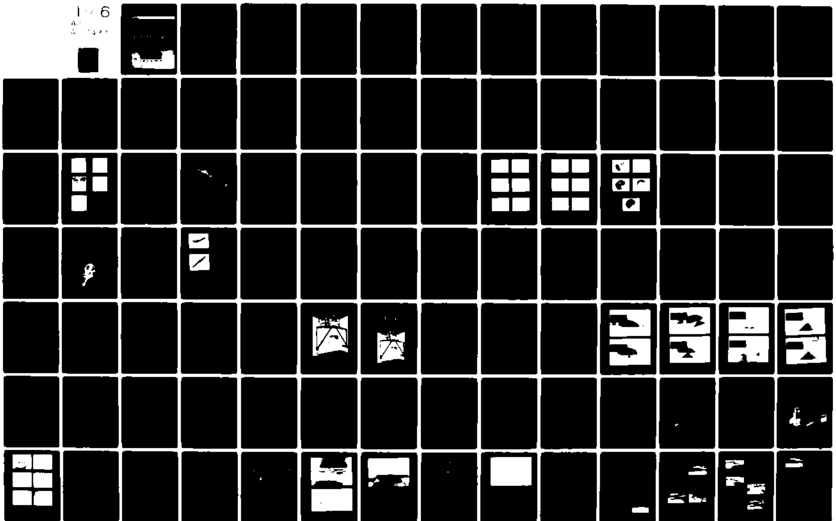

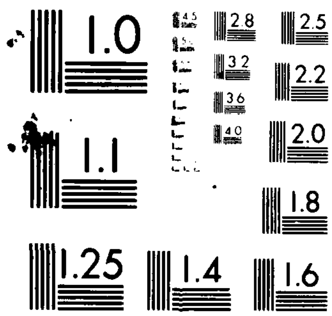


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# PROCEEDINGS

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2nd INTERSERVICE/INDUSTRY TRAINING EQUIPMENT CONFERENCE AND EXHIBITION

NSIA

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## FOREWORD FROM THE CONFERENCE CHAIRMAN

This is the Proceedings of the 2nd Interservice/Industry Training Equipment Conference held in Salt Lake City, Utah, November 18 through November 20, 1980.

As you read or seek reference from it after the conference, I want to be presumptuous that at least two thoughts will be rekindled.

One that the conference program was current and exciting and another more encompassing, that the dedication, long contained in the history of this conference, to making it THE Training Equipment Conference was shown to be continuing, even increasing.

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Ready, willing or not, we are launched headlong into the decade of the 80's; all the challenges projected by the prophets of the 70's abound and then some! Weapon systems are more complex; the need for well designed training systems and associated training equipment more vital. It is, therefore, incumbent upon all of us in the training equipment community to see that we are geared up to meet this need. This training equipment conference with the information we share with each other represents a key step toward meeting that objective.

There is a caution we in our business must observe as we prepare to meet the tasks of the 80's and beyond. Our colleagues, the operational equipment designers, talk of accomplishments and predict progress relating to systems with tremendous degrees of automation and high orders of reliability. We must guard against the lulling effect associated with these words that can cause a thought posture that the need and importance of training will diminish—even disappear. NOT SO! Man is and will be firmly in the loop. These new developments do help him; properly designed they do expand his capabilities, sometimes lighten his task load. The requirement for training the operator to handle the systems available so well that those actions he must take are almost involuntary continues to exist.

Training equipment design will also continue to be required to consider the situations that will exist when the operator must be trained to complete his mission (and here our associates who design operational systems will grind their teeth) when the operational system is in a degraded performance mode or even a partial failure mode.

This sums up to all of us in the business taking action to see that there is a continuing and expanding consciousness of the value and need for training equipment. This conference and these proceedings represent a significant portion of that action.

R. W. Layne
NSIA Conference Chairman

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# CIG DATA BASES; WHERE ARE WE HEADED?

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ABSTRACT

The rapid advancement in capabilities of computer image generation (CIG) visual systems has resulted in increased application of such systems from take-off and landing training to full-mission simulation. These full-mission applications dictate a need for the creation of high-fidelity data bases covering large geographical areas on the order of multiple thousands of square miles. As a consequence, the manual techniques employed in the past to create small, airfield vicinity data bases are not practical for generation of very large data bases. Clearly, some type of automated data base generation technique is required. Current trends are aimed at utilizing the Defense Mapping Agency (DMA) digital data base as source data and applying to it a computer transformation in order to arrive at a real-time CIG data base. However, current limitations of the DMA data, CIG system constraints, and training utility of the end product limit the amount of automation possible in the data base generation process. This paper discusses the evolution of the CIG data base generation process from totally manual methods to current trends toward full automation. Practical limits of automation and potential future developments are examined.

## INTRODUCTION

Since late 1973 when the cost of aviation fuel began to rise and availability became less certain, the Air Force has endeavored to reduce the number of training hours in the actual aircraft. Accordingly, the full-mission considerations of simulator training have become more important. Visual simulation has become a major contributor to the full-mission training capability in simulators. The most widely used method for generation of the visual imagery for Air Force simulators is that of Computer Image Generation (CIG). This technology employs high-speed, special purpose computational logic to generate perspective imagery using a mathematical model of the real-world as input data (data base). The problems encountered in determining the content of the data base, as well as limitations in the generation of the data base and the resulting impact on training capability are the subject of this paper.

## WHERE HAVE WE COME FROM?

### In the Beginning

A classical measure of the processing capability of the CIG system is the edge capacity. An edge is defined as the boundary between two separate surfaces in the displayed imagery. CIG systems acquired during the infancy of the technology (roughly 1962-1972) by NASA and the U.S. Navy could generate on the order of 240 to 512 edges. The data bases used by these systems were thus very small and low in detail. These data bases were all hand-modeled at relatively low cost in manhours. Their small size and simplicity made testing and debugging (correcting anomalies which cause the generation of incorrect scenes or distracting effects) a relatively simple task. However these early CIG systems, because of their limited power, were used for training only basic flying maneuvers such as take-off and landing.

In the late sixties and early seventies the dramatic progress in the electronic microcircuit industry was beginning to reflect on CIG technology. Image generators capable of processing 1000 to 2000 edges became available. Along with this growth in image generator capacity came the attendant growth in edge density and in the geographical area of coverage of the data base. The Air Force's Advanced Simulator for Pilot Training (ASPT) was perhaps the premier system developed during this time. The ASPT visual system had the capability to process up to 2500 edges from an originally delivered data base containing approximately 100,000 edges. The initial ASPT data bases covered an area of 500 square nautical miles and yet were still generated by hand using engineering drawings, blueprints, photos, maps and personal observations. Those features or objects which were deemed significant as cues for training were manually extracted one-by-one from the source data. The time required to intelligently fill a data base of this size with sufficient edges and lights to fully exploit the capability of this more powerful image generator was becoming significant. The ratio of data base cost to the total cost of the visual system was starting to rise.

The Air Force's Advanced Electro-Optical Sensor Simulation system (AEOSS) was developed in the mid-seventies as a tool to investigate not only E-O sensor simulation using CIG, but new image generation techniques as well. Although the AEOSS was a non-real time research oriented device, it had the capability to replay relatively complex imagery (containing over seven thousand edges) in real-time for evaluation. Perhaps the real significance of this system, however, was that it marked the first application of a fully automated technique for CIG data base generation. The terrain definition for the AEOSS data base was derived by fitting surfaces to the terrain elevation data provided by the Defense Mapping Agency (DMA) Digital Land Mass Simulation (DLMS) data base. DMA also provides a cultural data file to describe the topography of the terrain, but for AEOSS it was used mainly to define the locations of large water features (lakes, etc.) on the terrain. Some of the man-made cultural features were also transformed automatically, but this was done using a relatively gross approximation of the features with little detail. All of the detailed culture specifically required for the AEOSS system was modeled and inserted into the data base by hand. This becomes significant when one considers that the geographic area of coverage has been extended to 2500 square nautical miles.

More Systems

Although CIG technology was struggling to its feet in the early seventies, the impending fuel shortage was about to force CIG to take a giant leap forward. The 1973 Mid-East oil embargo had a significant effect on the price and availability of jet aviation fuel. The immediate reality for the Air Force and the rest of DOD was a gradual yet sizeable cutback in the amount of flying hours normally earmarked for training. The answer - use simulators to replace the lost training hours. The Air Force then embarked on a series of new simulator acquisition programs.

More Performance

Since in many cases the new simulators were to replace and no longer simply augment training in the actual aircraft, procurement specifications were written for devices having significantly higher performance capabilities than existing simulators of that time. Inherent in these specifications was a "full mission" training capability; the ability to rehearse a total mission from take-off to landing - all in the simulator. Visual simulation was a key to this capability. Take-off and landing and general cockpit procedures proficiency were no longer the only simulator training tasks to be dealt with. Low level navigation, aerial refueling, visual weapons delivery and aerial combat training via simulators were now firm requirements. Because of its inherent flexibility and rapidly growing capability, CIG was considered the visual simulation technology most capable of meeting these new requirements.

Along with the more powerful CIG systems capable of supporting full-mission simulation, requirements for data bases covering large geographic areas of the world began to evolve. Perhaps the most challenging data base requirements for a CIG visual system are tied to the Air Force's C-130 visual system procurement program.

## WHERE ARE WE TODAY?

Larger Data Bases

The C-130 visual system pilot production unit is being procured with three separate data bases. One of these data bases will be a relatively small (2,500 sq mile) area surrounding Barksdale Air Force Base. The other two data bases will each cover 40,000 square nautical miles in the vicinities of Little Rock (Arkansas) and Kirtland (New Mexico) Air Force Bases. The latter two data bases will contain the respective air bases as well as airdrop zones to allow for training in the following areas:

1. Ground operation
2. Takeoff, approach and landing
3. Formation flight
4. Low level navigation
5. Assault landing

It is the low level navigation requirement along with the large area of coverage which necessitates new data base generation techniques.

Since the C-130 flight simulator's radar landmass system was already using the DMA DLMS data base as source data, the decision was made to utilize the DLMS data base as one input for the visual system data base generation process as well. The one obvious benefit to be derived from using the common data source was correlation between the radar and visual subsystems, ie. terrain prominences and cultural features will be portrayed in the same geographic locations in both systems. The second and perhaps more significant benefit to be drawn from the use of the DLMS data base is its digital formal. No manual digitization would be required in order to insert cultural features found in the DMS data base into the CIG visual system data base, although the transformation program had to be expanded to provide this capability.

Thus, the complexity of a transformation program which formerly emphasized terrain transformation has been increased significantly with the addition of a more faithful culture transformation and the process of merging the resulting terrain and culture models. Even with this expanded capability, an enormous expenditure in manhours is required to customize the data base for training by manually adding training significant features not found in the DMA DLMS culture data.

Source Data Limitations

Truly, the final data base product can only be as good as the source data used to generate it. In fact the source data is the first problem encountered in the data base generation process. DMA's DLMS data base is the most comprehensive source of data currently available for use as source data for CIG data bases. The DLMS data base is a good source of data because it includes both real-world terrain elevation and cultural data, and will eventually be expanded to cover literally millions of square miles, including the continental U.S. as well as foreign countries.

Although the large area of coverage of the DMA DLMS data base makes it attractive for use as source data for visual data bases, one significant drawback does exist in the fact that, from the outset, the DLMS data base has been created to primarily support radar simulation. Hence only larger "radar significant" features are included in the culture file. Accordingly the DLMS data base does not include many types of features which are very significant from a visual navigation standpoint. This includes such features as roads, overpasses, railroads, and small streams.

Another limitation in the DLMS data base is a lack of any coloration or surface characteristic (texture) information. Also the size criteria which DMA uses to capture features in the DLMS production process limits the resolution of the displayed visual data bases to much less than that which is resolvable in current visual displays. Consequently, any area in the data base which requires high detail must be enhanced via a time consuming manual process using other sources of data.

Thus, there exists no single totally comprehensive source of data which provides the detail and accuracy required to model even take-off and landing type data bases, much less data bases to support the low-level navigation tasks required of the C-130 system. While the obvious solution is to selectively utilize inputs from a combination of several different data sources, it is precisely this solution which introduces some of the major problems currently being encountered in the generation of large data bases.

Registration

Since certain areas of CIG data bases often contain navigationally significant features which are not completely defined in the DMA DLMS data, these features must be obtained from a different source. There are alternate data sources such as Joint Operation Graphics (JOG) charts, Tactical Pilotage Charts (TPC), photos, etc. However, when additional features are extracted from any of these alternative data sources and inserted into the previously transformed data, registration with other features in the data base can become an almost insurmountable problem unless proper care is taken at the correct stage of the data base generation process. A case in point is the C-130 visual system data bases in which bridges are extracted from the DMA data, and streams and roads are placed in the on-line data base using JOG charts as source data. When extracting features from two different sources, each with its own accuracy tolerance, the result is predictable. For instance, a road may run up to a stream and miss the bridge by several hundred yards, if in fact the bridge traverses the stream at all. Several other such misregistration situations are possible, such as:

1. Dams to lakes
2. Streams to lakes
3. Roads to water features

These irregularities are unacceptable for navigational training and potentially require significant numbers of interactive manhours to insure proper registration. Manual interaction is a leading contributor to data base production costs, but at present there is no clear alternative to resolve these types of problems.

Real-Time Constraints

On the other end of the data base generation issue is the capability of the image generator to handle the data base content. Data bases must be generated with consideration of the target image generator's processing capacity. Failure to do so will more than likely result in system overload which is characterized by unacceptable streaking or breaking up of the video image. Thus, the goal in the development of any particular CIG system is to create a uniformly dense data base that will, in general, be tailored to load the image generator to an optimum percentage of its capacity without overloading it. This is not typical of past approaches where the image generator has been sized to handle the most dense, worst case areas of the data base which usually constituted a relatively small percentage of the entire geographical area of coverage. This approach guaranteed waste of a large percentage of image generator capacity whenever sparsely populated areas of the data base were traversed.

Several performance parameters of CIG image generators need to be considered during the data base generation process. The most important of these is the number of faces or edges which the system can handle. This, in conjunction with the field-of-view of the visual system, leads to an understanding of the edge or face density required in the data base to properly load the image generator. The number of edge crossings per raster line that the image generator can handle is also a parameter that influences allowable edge density in the data base. Finally, there is the consideration of mass storage for the data base. While not a problem at present, future systems with larger capacity and higher fidelity image generators and more complex data bases will impose new and more challenging requirements for data base storage and real-time retrieval. The only real concern is that the stored data base is adequate to optimally load the image generator and is capable of being accessed rapidly enough to allow real-time generation of the required scenes.

Other Considerations

Generation of acceptable on-line data bases is not assured by simply creating mathematically correct object definitions and avoiding conflict with image generator capabilities. Indeed a displayed data base may, upon initial static evaluation, look very acceptable. However, when the data base is applied to a real-time training scenario, the same displayed data base may be judged to be unuseable. When dealing with CIG systems, the relative acceptability of a data base and the concept of "realism" are not necessarily related. In order to accomplish training, the data base must, in conjunction with the image generator, provide adequate and "proper" visual cues to the aircrew. The proper cues vary for each different task. For take-off and landing, the relationship of the runway to the surrounding terrain and culture and the texture or character of the terrain surface may be most important. For low level navigation however, the occlusion of cultural features by other cultural features and the terrain profile is more significant. Also a low level navigation data base must include a sufficient number of cultural features to clutter the scene in order to train the navigator to discriminate between similar features in establishing checkpoints.

Another requirement for navigational training is consistency which can be exemplified by the ability of a student navigator to look at his chart and base the determination of a checkpoint on a feature on the chart, with full confidence that the feature in question will appear in the CIG data base for every occurrence on the chart. Dealing with this problem properly entails numerous hours devoted to manual processes. The pain involved can be eased by intelligently determining what features are navigationally significant and including all such features at the cost of eliminating other features whose presence makes the data base look more realistic, but adds no training value. Of course the determination of what is navigationally significant needs to be determined separately, to some extent, for each different data base area. This is illustrated on the C-130 by the fact that the Little Rock area is tree covered with numerous lakes and a moderate amount of man-made cultural detail. The Kirtland area, on the other hand, contains very sparse cultural content (approximately 8% of the number of features found in the DMA data base for the Little Rock area for roughly the same geographical area). In the Little Rock area, the lakes and trees are navigationally significant, while such features as farms and ranches are useful for their clutter value but are of secondary importance for overall navigation. In the Kirtland area, however, isolated ranches and windmills comprise a large percentage of the cultural detail and are primary navigational cues.

Coloration of features is a significant navigational cue and therefore is also an important consideration in data base generation. Subtle color differences between features cannot always be successfully inferred from source data but instead must sometimes be gleaned from personal observation or color photography.

One last consideration in the generation of large area data bases is the concept of homogeneity. The displayed data base must possess a distribution of features (detail) which is analogous to the real world. Concentration of features in an area of the on-line data base where the same relative concentration does not exist in the real world can lead to artificial cueing. Corridorizing of a data base is the practice of concentrating data base detail along a pre-determined flight path. While corridorizing can help to reduce the number of manhours required to build a data base, it does tend to limit the flexibility of use of the data base and can also result in artificial cueing; if most of the detail is clustered around one predetermined path through a data base, other missions with other routes of flight cannot be readily accomplished. Also if, while flying a mission along the preselected corridor, the pilot begins to inadvertently diverge from the prescribed path, the crew will immediately be alerted to his error by the sudden reduction of scene detail away from the corridor.

In many regards data base creation is as much an art as it is a science and the above comments are intended to illustrate that a rigid, cookbook approach to data base generation is not usually sufficient. Even if all the mechanical registration type problems are eventually solved, it appears a certainty that some amount of modeler interaction during the data base production process will always be required. The objective, then, must be to minimize modeler interaction by maximizing the amount of automation used in the basic feature extraction process and leave any manual interaction to debugging and fine tuning enhancements.

## WHERE ARE WE HEADED?

It is clear that there are many unsolved problems in the visual data base generation process. Furthermore, the current problems are only likely to worsen as technology advances and image generator capacity increases along with the demands on the data base. Thus, data base production costs can only be expected to keep rising. What can be done about it? The Air Force is currently pursuing several efforts in order to deal with these problems.

Data base commonality is one potential solution to the problem. In past systems, radar and visual data bases as well as any sensor data bases have all been developed independently of each other. The hand-modeled areas and processes that require manual interaction are and will continue to be fairly expensive parts of the process. It is possible that generating these areas once and including appropriate features/descriptors for visual, sensor, and radar all in the same data base could ease the data base generation manpower requirements. The tradeoff potentially involves more storage for the on-line data base if parameters which are not being used for a certain application are built in. However, a secondary translation program could be applied to extract a specialized data base from the universal common data base and thereby eliminate the overhead.

Data base portability is another idea under consideration by the Air Force for use in future systems. This concept would require that all future data bases be generated to the highest detail or fidelity possible and described in a high-order type data base language. This data base could then be compiled (or filtered) for other simulators or for other types of missions in the same simulator by specialized software which uses the high level description as input and develops a tailored data base for a particular application on a target visual system. Each feature in the high-level data base would contain appropriate importance descriptors for filter survival based on the type of mission to be trained and the capacity of the intended image generator. This technique, combined with a discriminator capability in the image generator to monitor image generator loading and select features from the on-line data base in priority (or importance) order, should save on data base generation expense and at the same time provide for better image generator loading and overload prevention in CIG visual systems.

There is also the consideration of future alternate data sources. Although at present the DLMS data base is the best source of information available for CIG data bases, there is the possibility that new and better sources of data may be developed in the future. One must keep in mind, however, that it will probably take requirements by potential users other than the simulator community to make the development of such a "customized for training" data base worthwhile, considering the great expense involved in data base construction.

One future possible source is the DMA level V (for visual) data base currently being planned. Level V will involve the addition of features and descriptive parameters to the DLMS data base for the purpose of better defining features and surface characteristics which are navigationally or perceptually significant for visual system use. Level X is a planned extension of Level V which will provide relatively small areas of high detail within Level V. However neither Level V nor X is expected to be implemented (except possibly for demonstration purposes) for approximately ten years.

In summary, the technology of computer image generation and attendant advances in data base generation for CIG has seen tremendous advances. Many more advances are currently being envisioned, planned or implemented. But in the final analysis, it is probable that some degree of manual enhancement or editing will always be required nc matter what the capacity of the target image generator or the intelligence of the transformation program is.

## ABOUT THE AUTHORS

Mr Robert W. Beck is a Program Engineer at Aeronautical Systems Division (ASD) Wright-Patterson AFB, Ohio. He has been involved in the development and acquisition of several simulator visual systems for the U.S. Air Force including the Simulator for Air-to-Air Combat and the B-52 Weapon System Trainers. He is currently assigned to the Simulator System Program Office at ASD as the lead engineer in the acquisition of the C-130 simulator visual system. Mr Beck received his B.E.E. degree from the University of Detroit and an M.S. degree in Systems Engineering from Wright State University

Mr Michael R. Nicol is a visual systems engineer for the Visual and Electro-Optical Branch of the Air Force Aeronautical Systems Division, WPAFB, Ohio. He is currently involved in the engineering of the data bases for the C-130 visual system, and has previously been involved in the development and use of the Airborne Electro-Optical Sensor Simulation (AEOSS) system for the Air Force Human Resources Laboratory. Mr Nicol received his B.S.E.E. degree from Ohio Northern University, and is completing an M.S. degree in Digital Engineering/Computer Science at the Air Force Institute of Technology.

AUTOMATIC TRANSFORMATION OF THE DMA DDB

FOR REAL-TIME VISUAL SIMULATION

By

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for Data Base Software

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ABSTRACT

This visual data base transformation program automatically transforms the Defense Mapping Agency Digital Data Base (DMA DDB) into a data base for real-time simulation of the B-52 electro-optical viewing system. The user reviews the source data and specifies edge budgets, error tolerances, and visual/infrared models for DMA planimetry feature classes. The DMA DDB is read and reblocked into standard geographical areas; data from different manuscripts, levels, and releases are merged into a composite source file. The user may edit the composite source. Then planimetry and terrain are independently modelled into visual/IR representations and progressively simplified (levelled) to meet the specified edge and error budgets at several levels of detail. The levelled planimetry and terrain are integrated into a combined scene model and reformatted for real-time use. Utility software facilitates production management and configuration control. Significant advances include automatic level of detail generation, terrain modelling, planimetry/terrain integration, and a 100-fold speedup in data base generation.

INTRODUCTION

As flight simulator training scenarios become more complex and extensive, so must the visual data bases which support them, straining the capabilities of manual modelling techniques. The LINK Division of the Singer Company has developed for the B-52 Weapons System Trainer (WST) a computer program which automatically transforms the DMA planimetry and terrain data bases into a data base which supports real-time simulation of visual and infrared (IR) sensor displays (1, 2, 3). This paper describes the concepts and operation of the transformation program, illustrates the transformation of a typical area as shown in Figure 1a, and discusses the advantages and problems of automatic transformation.

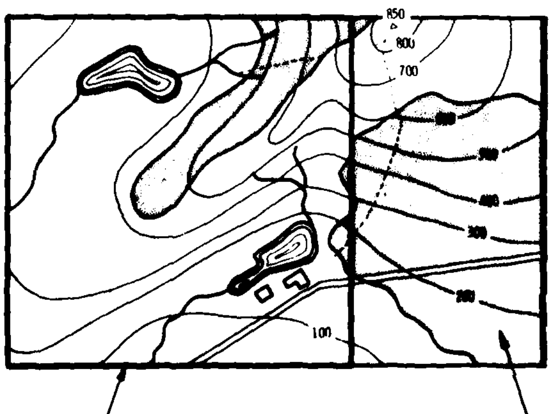



*Figure 1a*
Map of Example Area

The B-52 WST is designed to provide full-mission, full-crew training, including day and night low-level penetration during Emergency War Order and training missions. Low-level penetration includes terrain avoidance, low-level navigation, bomb damage assessment, and low-level gravity weapon delivery. These tasks are supported by visual (out-the-window) and electro-optical sensor displays within a mission corridor of up to 130,000 square miles. (Other mission phases and aircraft systems are simulated, but are not important to this paper.)

The electro-optical viewing system (EVS) consists of forward-looking infrared (FLIR) and steerable low-light level television (STV) cameras in two pods under the aircraft nose, and control and display consoles at the pilot, copilot, and radar navigator stations. Both sensors can be steered in elevation and azimuth and provide wide and narrow fields of view. The FLIR is sensitive to both reflection and thermal emission; diurnal variations are apparent and are included in the simulation.

The simulated visual, STV, and IR scenes are generated in real-time by the VISULINK® Digital Image Generator (DIG). The DIG extracts from a visual data base the parts of the scene relevant to the pilot eyepoint computed by the flight simulation; computes a correct perspective view; removes distant objects occulted by near objects; and displays the resulting scene. The same data base is used for visual, STV, and IR simulation; separate color, intensity, and IR codes are provided, but the geometrical model and all other components are the same.

The visual and EVS simulations are correlated with flight simulation and other airrraft systems in real-time during training; a stand-alone mode allows independent operation from a diagnostic control panel.

Dynamic scene levelling simplifies those parts of the scene far from the eyepoint; this concentrates detail in the foreground and makes the most efficient use of DIG capacity. Several levels of detail are constructed during transformation; one is selected and displayed during real-time operation.

Planimetry data is provided on magnetic tape by the Defense Mapping Agency/Aerospace Center (DMAAC) and defines planimetric features such as lakes, cities, forests, roads, and buildings in digital form (4). Level I data covers large areas of the earth's surface at low resolution; Level II data covers important small areas at high resolution. Each tape typically covers a rectangle in latitude/longitude from 1° X 1° to 1° X 6° and is divided into manuscripts ranging from 7½' X 7½' to 30' X 15'. Each manuscript describes all the planimetric features within its defined area. Figure 1b shows a sample manuscript corresponding to the outlined area in Figure 1a.

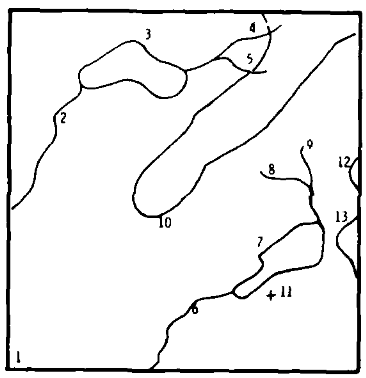



Figure 1b
Example Planimetry Manuscript

A feature is uniquely identified within its manuscript by a feature analysis code (FAC #). If two features overlap, the one with the higher FAC # masks the other. The predominant height of the feature gives its characteristic height above the terrain or underlying feature. The feature identification code (FID) describes the kind of feature: quarry, smokestack, railroad, bridge, residence, navigation aid, runway, lake, shoreline, etc. The surface material code (SMC) describes the composition: metal, stone, water, sand, soil, marsh, snow/ice, etc.

The feature type distinguishes different feature geometries: a point feature is digitized as a set of isolated points supplemented by orientation, length, width, height, FID, and SMC. A lineal feature is digitized as a chain or open polygon supplemented by width, height, FID, and SMC. An areal feature is digitized as a closed counter-clockwise polygon supplemented by height, FID, and SMC.

Terrain data is also provided by DMAAC and defines terrain elevations in digital form (4). Each tape covers from 1° X 1° to 1° X 6°; a manuscript always covers 1° X 1°. The terrain elevations are sampled at a rectangular grid in latitude and longitude. The grid spacing in latitude is 3 arc-seconds (about 300 ft); the grid spacing in longitude varies from 3 to 18 arc-seconds (about 300 ft) depending on latitude. Unknown elevations are designated by a special code. Figure 1c shows a sample manuscript. (The grid spacing is distorted for clarity.)

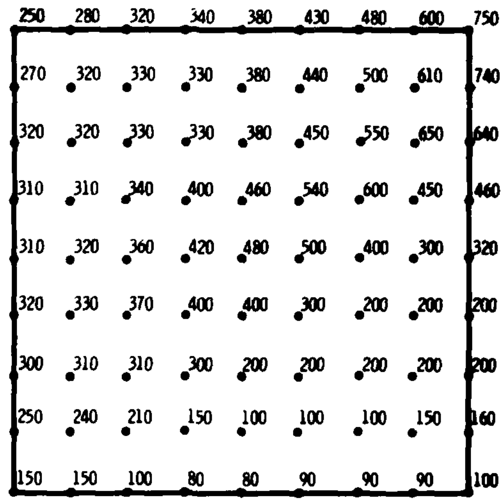



Figure 1c
Example Terrain Manuscript

The remainder of this paper describes the program which transforms the DMA DDB into a visual data base for real-time simulation. It outlines the organization of the program and of its intermediate and output data bases; describes the processing steps performed; discusses the significant advances to the state of the art; and identifies areas for further development.

## PROGAM ORGANIZATION

The transformation program consists of about 100,000 source lines and is written almost entirely in FORTRAN or RATFOR (5). It includes all the functions necessary to create from the DMA planimetry and terrain a visual/IR data base to be displayed in real-time. Most processing is done in batch mode; a few functions depend on human judgement or perception and are done interactively.

Figure 2 shows the overall organization of the transformation program and indicates the primary data, control, and operator interfaces. The functions and interfaces will be described briefly here and in detail in the following sections.

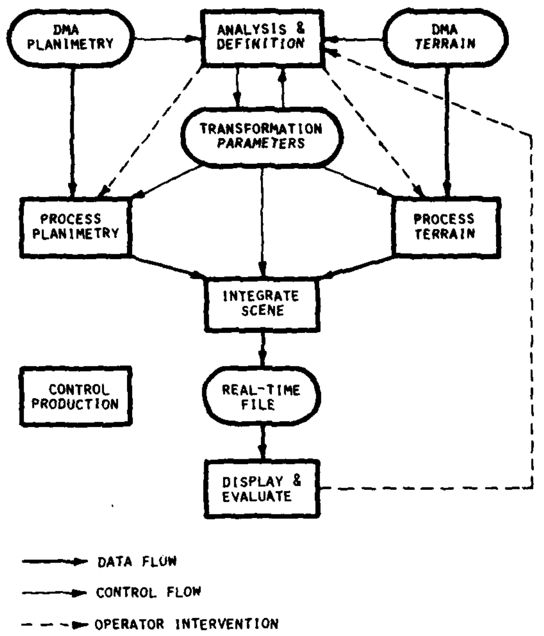



Figure 2
Overview of Transformation Program

The process begins with the DMA planimetry and terrain described in the previous section. The data base designer uses interactive analysis and definition programs to review the contents of the DMA DDB, define the visual representation for each feature class, and select parameter values to control the automatic transformation process.

Planimetry processing software converts the DMA planimetry to a standard internal format; merges the contents of adjacent manuscripts, levels, and updates; allows the designer to edit the planimetry; selects a visual/IR model for each feature as directed by the transformation parameters; and creates levels of detail. Planimetry edit is interactive; all other steps are batch.

Terrain processing software almost directly parallels planimetry: it converts the DMA terrain to a standard internal format; merges the contents of different manuscripts; allows editing; constructs a polyhedral model of the terrain; and creates levels of detail. All steps except editing are batch.

Scene integration software combines planimetry and terrain models into a unified scene model: it divides each planimetry feature into pieces contained in a single terrain face; resolves overlaps among features; assigns elevation values to the planimetry; builds the visual model already selected; merges planimetry and terrain; converts the scene to the real-time display format; and creates the directories and linkages necessary to support real-time retrieval.

Display and evaluation is not properly part of the transformation program, but is important to the data base development process. It consists of real-time display during flight simulation and (more importantly) for visual evaluation of the data base. If errors or weaknesses are found, the designer can repair them by editing the planimetry or terrain or modifying the transformation parameters and then retransforming the affected areas.

Production control software includes various utility functions to support and manage the production process. It creates and maintains data base directories; tracks the processing of manuscripts and area blocks; tracks data base configuration; reports processing errors; and generates a production log.

## DATA BASE ORGANIZATION

The data base can accommodate up to 100 million square miles of visual data in multiple disjoint areas anywhere in the world; its organization is shown in Figure 3. All fixed features are assumed to be between 2000 ft below and 30,000 ft above mean sea level.

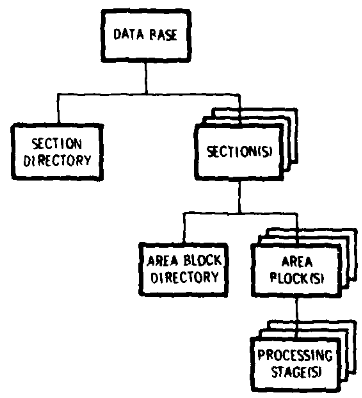



Figure 3
Data Base Organization

The surface of the earth is divided into fixed geographic areas called area blocks. An area block is triangular, covers about 25 square miles, and is the basic unit for processing, storage, and retrieval throughout transformation and real-time display.

The data for each area block is divided into separate files resulting from each stage of processing.

A section is a set of area blocks which fit on a single disk pack. Sections are defined by the data base designer and typically include 200-500 area blocks or 5,000 to 12,500 square miles. A standard section holds a compact set of area blocks and is used for most processing. Non-standard sections hold input planimetry and terrain until they can be reblocked into standard sections.

## ANALYSIS AND DEFINITION

Analysis and definition software includes programs which the data base designer uses to review and analyze the contents of the DMA DDB, to define the visual/IR representation of feature classes, and to create command files which control the transformation process.

Analysis software provides the capability to list planimetry feature attributes and coordinates; list terrain elevations; plot planimetry or terrain; and analyze the statistical distribution of feature type, size, or attribute values. Analyses may be done for all features in a manuscript or for classes of features defined by type, position, or attribute values.

The planimetry conversion table is created by the designer and defines the desired visual and IR representation for planimetry features. It is indexed by FID, SMC, and type and specifies the desired model class, specific library or parameterized model, color, IR class, significance (relative accuracy requirement), and preference (relative inclusion priority).

Four classes of models are provided, as shown in Figure 4: a library object is modelled by hand prior to transformation and can be inserted anywhere; it may be as complex as desired. Parameterized objects are less complex and are built automatically by software to a specified height, length, width, and orientation. Carpets are still less complex and are built automatically to a specified height and outline. Paint-ons are simply colored outlines laid directly on the terrain. Finally, a feature may be omitted completely.

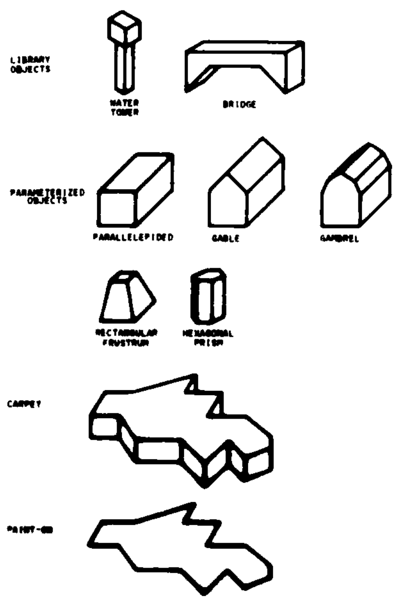



**Figure 4**
**Visual Models**

The IR class describes the characteristic amplitude and lag of thermal variations relative to solar illumination; it is used to simulate the diurnal variation of infrared sensor imagery.

Significance identifies features such as navigation landmarks for which the correct shape is important; preference identifies features which are important to include in the scene. If the scene must be simplified to match DIG capacity, these features will be the last to be simplified or discarded.

Command files are created by the designer to control transformation and are entered as a list of free-form commands and parameter assignment statements. The parameters define the planimetry conversion table to be used, number of levels of detail to be built, edge and error budgets for each level, the target DIG, and various special parameters.

## PLANIMETRY PROCESSING

Planimetry processing is shown in Figure 5, which traces the processing steps that convert the DMA planimetry into a visual model. Figure 6 illustrates the output from three key steps.

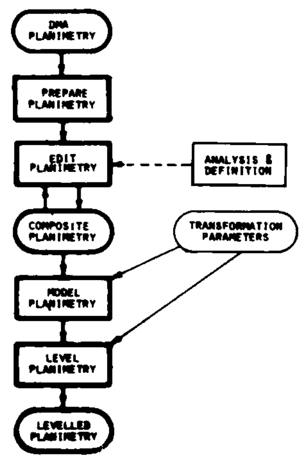



Figure 5
Planimetry Processing

Planimetry preparation software reads selected manuscripts from magnetic tape, verifies that all features are in proper format, and converts it to an internal format designed to facilitate editing and transformation. It also divides the manuscript into area blocks and allocates features to the area blocks they overlap. The points where a feature crosses an area block boundary are marked to assure continuity even though area blocks are processed independently. Finally, it merges the manuscripts and levels which overlap each area block. If manuscripts overlap each other, the designer must select one to define the overlap region.

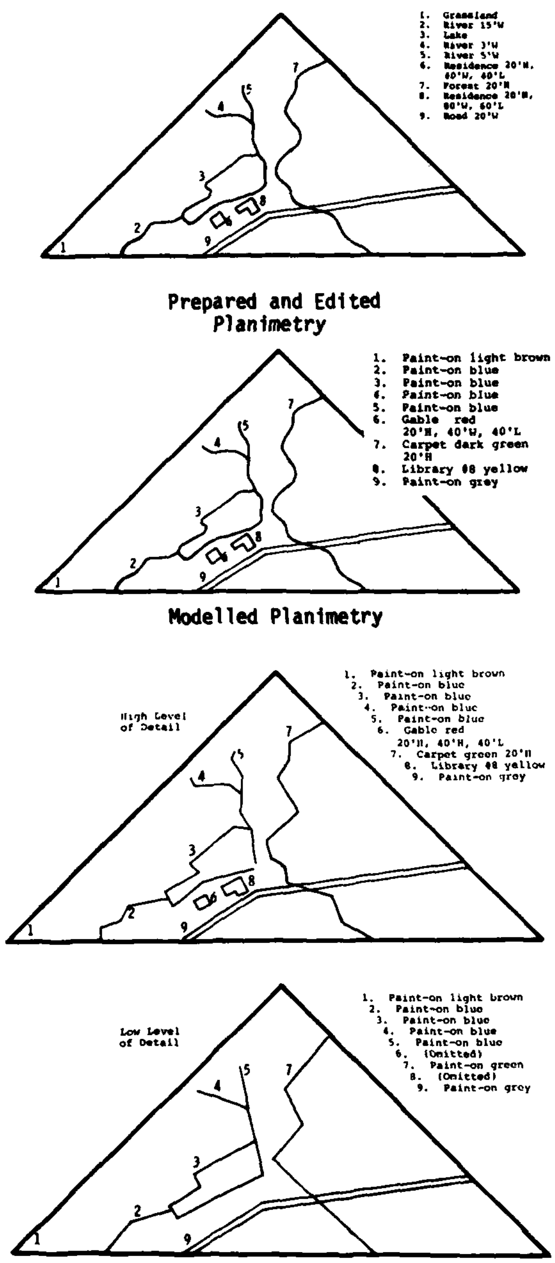



Figure 6
Key Planimetry Processing Steps

Planimetry editing allows the designer to insert features not included in the DMA DDB or correct any errors. The designer can select features by identifier, position or attributes; print or modify feature attributes; plot or digitize feature coordinates; and create or delete features. The program uses a Tektronix 4014 graphics terminal for graphical interaction.

The prepared and edited planimetry (composite planimetry) is retained to permit DMA updates, further editing, or retransformation with new parameters.

Planimetry modelling selects a visual/IR model for each feature, using its feature identification and surface material code to index into the planimetry conversion table. It also identifies and passes to terrain processing hydrographic features (lakes, rivers, etc.) which must be correlated with terrain modelling.

Planimetry levelling reduces the scene complexity to match the display capacity of the DIG and produces several levels of detail to use that capacity most effectively: the most-detailed version will be displayed near the viewer and less-detailed versions in the distance. The complexity is reduced by removing insignificant features; degrading the representation from library object to parameterized object to carpet to paint-on; or by simplifying the feature outline. Features marked as significant or preferred will be the last to be simplified or discarded.

## TERRAIN PROCESSING

Terrain processing is illustrated in Figure 7, tracing the conversion of the DMA terrain into a visual model.

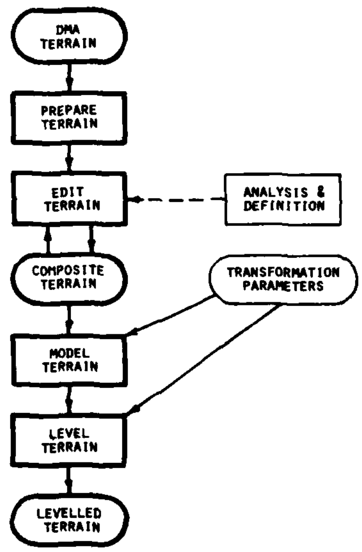


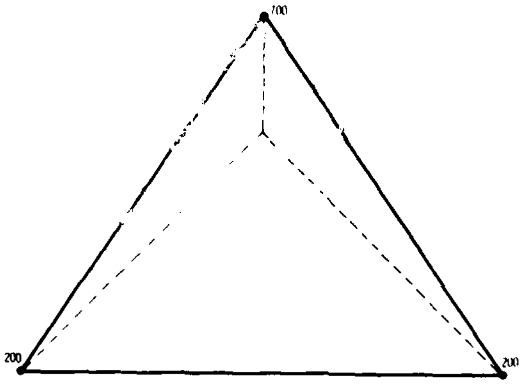

Figure 7
Terrain Processing

Terrain preparation reads selected manuscripts from magnetic tape, verifies that they contain no format errors, and converts them to an internal format. It divides the manuscript into area blocks and allocates elevation gridposts to the area blocks they lie in. Gridposts on or near an area block boundary are saved in all adjacent area blocks to assure continuity. Finally, it merges the manuscripts and levels which overlap each area block. If two manuscripts overlap, the designer must select the dominant one.

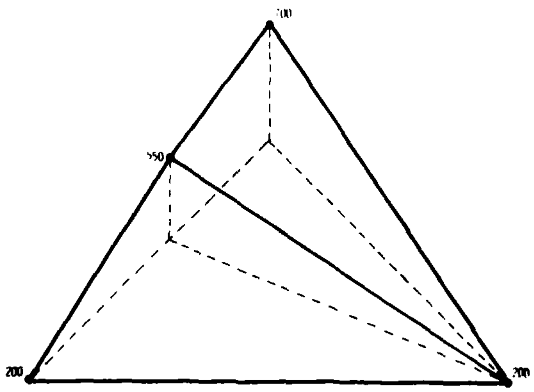
Terrain editing allows the designer to inspect or modify terrain elevations before transformation. He may plot perspective views of the terrain and print or modify elevation posts.

The prepared and edited terrain (composite terrain) is retained to permit DMA updates, further editing, or retransformation with new parameters.

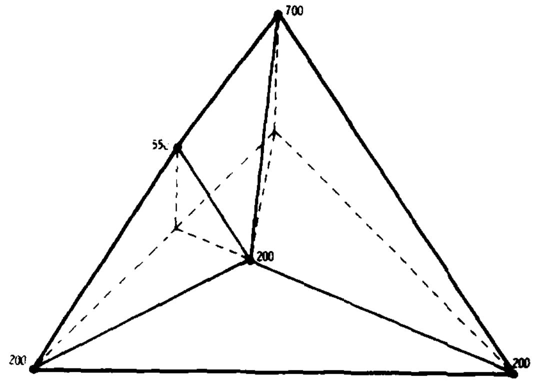
Terrain modelling builds a sequence of visual models by successive approximation to the given elevations as shown in Figure 8. Each model is a continuous polyhedral sheet of triangular faces; vertex elevations are determined by interpolation in the given elevations. The first model is the plane determined by the three vertices of the area block. This triangle is recursively subdivided into two smaller triangles by a vertical cutting plane through one vertex; the elevation of the new vertex created is determined by interpolation in the given elevations. If the new vertex is not on the edge of the area block, a second cutting plane is added from the new vertex to the opposite vertex of the adjacent triangle.




First Terrain Model




Second Terrain Model




Third Terrain Model

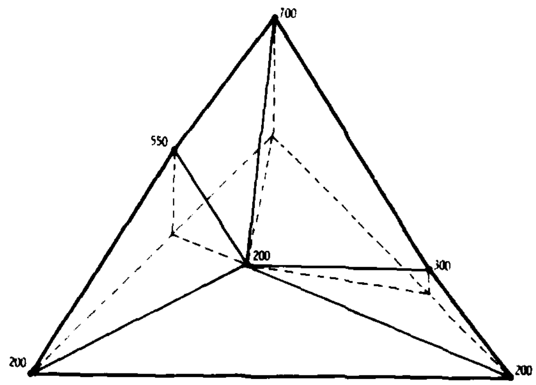



Figure 8
Final Terrain Model

Any of several heuristics are used to select at each step the triangle to subdivide and the cutting plane to use. Several conflicting requirements must be balanced: the model should match the terrain as closely as possible for each number of faces; the model must correspond correctly to hydrographic features; excessively thin triangles should not be generated; and models must be continuous across area block boundaries.

Terrain levelling selects from this sequence of approximations a set of models which match the display capacity of the DIG. As with planimetry, the most-detailed version is used near the viewer and less-detailed versions in the distance.

## SCENE INTEGRATION

Scene integration is diagrammed in Figure 9. Figure 10 illustrates the output from two key processing steps. Each level of detail is integrated in turn.

Planimetry division divides each planimetry feature into pieces, each of which is contained on a single terrain face. Library and parameterized objects are not exempt: they must be divided to support real-time occulting.

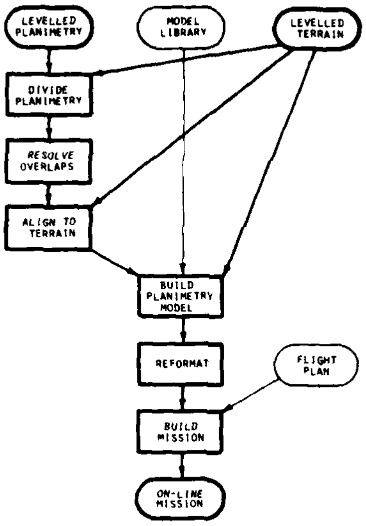
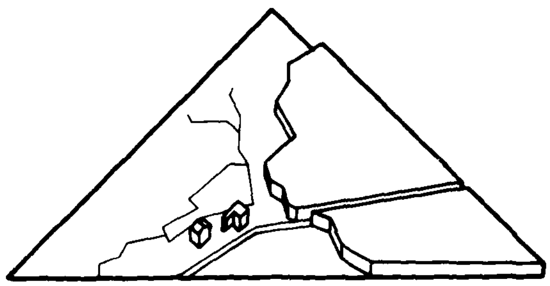
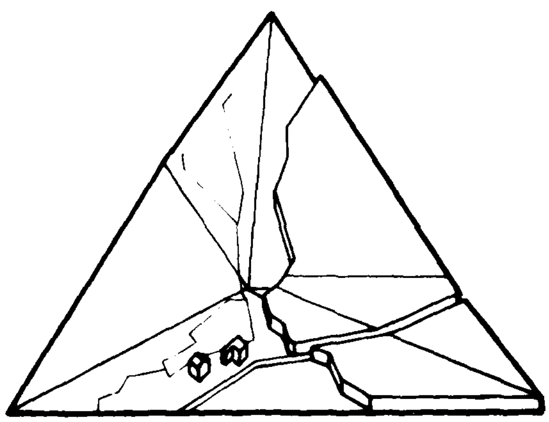



Figure 9
Scene Integration



Built Planimetry



Integrated Scene

Figure 10
Key Scene Integration Steps

Overlap resolution tests each terrain face for overlaps among the feature pieces lying on that face. If any overlaps are found, the feature with the highest FAC # has priority. Depending on the visual representation of the features involved, the masked portion of the lower feature may be removed, the lower feature may be assigned a lower occulting priority, or the higher feature may be elevated to rest on the lower.

Terrain alignment sets the elevation of each feature piece so that it rests on the terrain model. Each vertex of a paint-on or base vertex of a carpet is set to the terrain model elevation at that location; thus a paint-on or carpet will slope to follow the terrain. A library or parameterized object is elevated until the center of its base coincides with the terrain; it remains horizontal and any part below the surface is removed.

Model building creates the visual models selected in planimetry processing: library objects are copied into the scene; parameterized objects are built to the specified parameters; and carpets are raised above the terrain and provided with sidewalls of the specified height. Paint-ons require no construction. All planimetry models are added to the terrain model.

Reformatting converts the completed scene into a format designed to support real-time display and to use minimum file space. In addition, it computes several attributes and data structures needed to improve real-time efficiency and capacity.

Mission building selects the area blocks required to support a selected flight path and builds the directory structure needed for real-time retrieval. A typical mission will occupy several 300MB disk packs. Two packs are on line at any given time; as the aircraft flies they are alternately exchanged for other packs containing the new areas entered.

## DISPLAY AND EVALUATION

Display, evaluation, and revision are illustrated in Figure 11. The visual scene is displayed on a test monitor, out the cockpit windows, or on the EVS monitor in the cockpit. The display is normally integrated with flight simulation and is correlated with all other simulated systems. Stand-alone operation is also provided; scene viewpoint and display parameters are controlled at a visual system diagnostic control panel.

The display is evaluated visually. If it is not satisfactory, corrections are made by adjusting the transformation parameters, editing the planimetry, or editing the terrain. Then the area blocks which have been modified must be retransformed; the rest are unchanged.

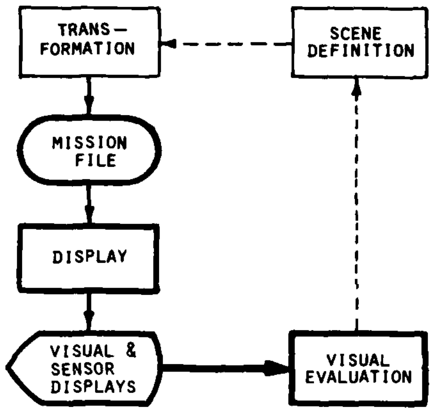



Figure 11
Display & Evaluation

## PRODUCTION CONTROL

This program is used to produce very large data bases; management, production logistics, and configuration control required careful attention.

Except for edit programs and visual evaluation, the transformation program operates in batch mode. The data base designer prepares command files which specify the area blocks to be transformed, the process steps to be done, and the parameters which will control the result. Once started, the program requires operator intervention only to mount tapes or change disk packs.

The program includes comprehensive checks on the consistency of input and intermediate files and on its own operations; if any check is not satisfied, an error message is printed out. Warning messages report conditions which are legal but suspicious; fatal errors report illegal conditions. If the effect of a fatal error is limited to a single feature or area block, the program will bypass that feature or area block and continue; only if continuation is impossible or risks damage to permanent files will the program stop. The error message will describe the error and will identify the specific erroneous area block or feature.

Each production run is automatically assigned a unique Production Control Number (PCN) and prints out a production log as a permanent historical summary of that run. The production log identifies the PCN of the run, the program version, the value of each input parameter, any error messages, run statistics, and the name and PCN of each input file.

Complete tracking of all intermediate and output files is provided. Each file contains the PCN of the production run which created or last updated it. The corresponding production log lists all relevant information, including the name and PCN of each input file. Then the production log for each input can be examined, and so on back to the original DMA manuscript.

In addition, the composite planimetry and terrain files identify the DMA manuscripts included in each area block and the area that each manuscript covers; each feature can be traced back to the original DMA manuscript and feature.

## SIGNIFICANT ADVANCES

The program described here has demonstrated several significant advances over previous techniques for the construction of visual data bases.

Utilization of the DMA DDB: The DMA DDB covers most of the United States and parts of the rest of the world, and is intended for tactical planning and radar simulation. The transformation program makes this data base available for visual and electro-optical simulation and facilitates correlation with other sensors based on the same DDB.

Automatic terrain modelling: The DMA DDB describes the terrain with high resolution. The transformation program builds a model of this terrain which can be displayed in real-time. The algorithm used can easily be extended to use other regular or irregular elevation grids. The need for specially-trained data base modellers is reduced.

Parameterized and library objects: The DMA DDB specifies little about the actual shape of a point feature. Parameterized objects provide the automatic construction of objects that meet the given length, height, and width. A selection of generic shapes allows the differentiation and visual identification of different feature classes. When a feature needs to be more complex, library objects allow the insertion of 3D models designed manually.

Automatic level of detail generation: Levelling improves apparent scene content by removing unresolvable or less resolvable detail from the background and adding more detail to the foreground. The transformation program automatically generates levels of detail for both planimetry and terrain.

Planimetry/terrain integration: Planimetry is normally mapped as if it were projected onto mean sea level, and is conveniently processed in this form; the terrain is processed independently. The transformation program automatically integrates the planimetry and terrain models into a scene model. This technique separates and simplifies the processing of planimetry and terrain without sacrificing the ability to create an integrated scene.

Large area update: DMA issues updated manuscripts from time to time. The transformation program can read these new manuscripts and retransform the modified area blocks without affecting the rest. This allows the data base to be kept current with minimum effort.

World-wide transformation: The data base coordinate systems, directories, and structure have been designed so that the transformation program can process data anywhere in the world. A round earth model provides good correlation with navigational systems. In addition, the data base is designed to accommodate the processing, retention, and use of data bases containing up to 100 million square miles.

Radical improvement in productivity: The transformation program can generate fully-debugged data bases about 100 times faster than previous manual techniques, depending on scene complexity and degree of manual enhancement. Furthermore, automatic transformation is still in its infancy, and significant further improvements can be expected.

Configuration tracking: A data base will be transformed from many DMA manuscripts, involve many sets of transformation parameters, and will gradually evolve as updated manuscripts and manual enhancements are incorporated. Every file can be traced back through the production log, ultimately identifying each original manuscript, intermediate file, program run, and parameter value involved in the creation of that file. In addition, each planimetry feature can be traced to the original DMA manuscript containing it. These techniques provide a permanent record of how a data base was built and facilitate the diagnosis and backtracking of errors.

## FURTHER DEVELOPMENT

The transformation program provides a new order of capability; however, it also reveals a few areas in which it is not yet known how to effectively use these capabilities or where the results are not yet as good as manual techniques. LINK has already begun further development of the transformation program to realize the full potential of automatic transformation.

Terrain fidelity: The present terrain modelling algorithm is controlled by the elevation error between the input and the model. As a result, it tends to build an accurate model (within the edge budget) but often fails to reproduce the visual appearance (or fidelity). Since many pilot tasks seem to depend more heavily on terrain fidelity than on elevation accuracy, more work is being done to identify the determinants of terrain fidelity and to develop algorithms that preserve fidelity.

DMA Planimetry: The DMA DDB was originally designed to support radar landmass simulation. The terrain DDB is readily usable for visual or electro-optical simulation, but the planimetry DDB has definite limitations. First, it contains little information on 3D shape, color, or IR characteristics. Second, it often omits features such as roads or rivers which are important visually but not on radar. Third, in many areas it does not contain sufficient features to support low-level flight. Fourth, the data is sometimes old and does not include significant features built recently. The transformation program cannot solve these problems, but work is being done to improve its edit and analysis capabilities and to incorporate data from other sources into the final scene.

Manual enhancement: The present transformation program does not provide for the insertion of entirely hand-modelled areas such as airports and limits manual enhancement of the transformed scene. Since DMA does not provide adequate detail to support take-off/landing scenes or tactical air-to-ground scenes, these must be entirely hand-modelled or manually-enhanced transformed scenes. More work is being done to develop the capability to combine automatic and hand modelling and to take full advantage of both.

## ACKNOWLEDGEMENTS

The work described in this paper was funded in part by the Air Force Aeronautical Systems Division under Contract F33657-77-C-0176.

This program is the product of many minds and hands working in concert. Significant design contributions were made by Bruce Robinson, Richard St. Thomas, Steve Berman, Allan Stenger, Lee Casuto, and Jerry Keeran. Bill Michaels and Bruce Robinson provided supervision.

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## ABOUT THE AUTHOR

Mr. Paul Hughett is a Lead Systems Engineer for Data Base Software and is responsible for requirements analysis and conceptual design of data base software. He has B.S. and M.S. degrees in Computer Science from Massachusetts Institute of Technology.

# AUTOMATION OF DATA BASE DEVELOPMENT IN COMPUTER IMAGE GENERATORS

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## ABSTRACT

Military requirements for large scale training missions on computer image generation (CIG) systems have placed increased emphasis on the CIG data base development process. General Electric produces large scale data bases in a semi-automatic process involving the transformation and enhancement of Defense Mapping Agency digital data bases into CIG scene descriptors. The enhancement process is the limiting factor in the evolution of a fully automated data base development system, and suggests a requirement for a single source data base. Future General Electric CIG systems will incorporate automation technology to allow for low cost generation of visual scenes meeting strategic applications of specific weapon systems trainers.

## INTRODUCTION

The emergence of computer image generation (CIG) in aircrew training as a multimillion dollar industry is primarily attributable to advances in electronic technology. Recently, however, CIG manufacturers have diverted research and development activities from computer hardware improvements to an increasing emphasis on the development of sophisticated techniques used in the generation of mathematical descriptors supporting simulation displays. These CIG data bases supply the necessary scene content constituting such cockpit panoramas as radar, forward looking infrared radar (FLIR), low light television (LLTV), and "out the window" visuals.

While early simulators provided visual cues for aircrew training in various airport (and aircraft carrier) maneuvers, more recent simulator systems have undertaken the portrayal of large geographic areas containing sufficient scene detail to support low altitude visual navigation. The ultimate goal of this development trend appears to be the manufacture of aircraft simulators capable of global flight paths arbitrarily selected by the flight instructor.

The complexity arising from the real time retrieval and display of high detail scenes has placed an enormous burden on the design of CIG hardware, and has forced most manufacturers to combine large core memory storage with high speed parallel processing in order to generate adequate cockpit displays.(1) In most cases, however, the industry has overlooked problems associated with preparation of the CIG data base itself. While data bases in early CIG systems were prepared in the tedious fashion described by Sutherland,(2) experience has shown that the manual preparation of large scale data bases is both expensive and impractical. It seems evident that overall progress in the CIG technology now relies on the total automation of the data base development process.

## HISTORICAL BACKGROUND

General Electric's Electronic Systems Laboratory developed the first computer image generator in 1958. This primitive device produced a regular line pattern over a ground plane to create the illusion of motion, but was clearly inadequate as a practical training tool. Subsequent CIG systems produced by General Electric and other manufacturers have shown significant progress in the enhancement of detail in the CIG displays.

Scene detail, in the language of the industry, is measurable by counting the number of visible edges displayed by the CIG at a given instant during real time operation. As is illustrated in figure 1, the growth in the number of displayed edges in various General Electric systems has been virtually exponential over the last 12 years. It is no coincidence that this growth curve parallels the exponential miniaturization of computer components arising from technological advances in medium and large scale electronic integration. The growth in complexity of CIG data bases, on the other hand, is small by comparison. In fact, figure 2 indicates the number of environment edges contained in General Electric CIG data bases actually declined after 1974.

The disparity apparent in the evolution of CIG hardware versus CIG data bases arises from the modest applications around which early CIG devices were designed. These products were intended primarily for use in landing/take-off maneuvers, and as such, required only a single airport complex in the data base environment. More recent projects have reflected a change in this application philosophy, and have encouraged expansion of flight scenarios to include air-to-air combat, in-flight refueling and low altitude navigation. One current aircraft simulation, for example, will require a supporting data base portraying a geographic area of 40,000 square miles. The generation of a data base of this

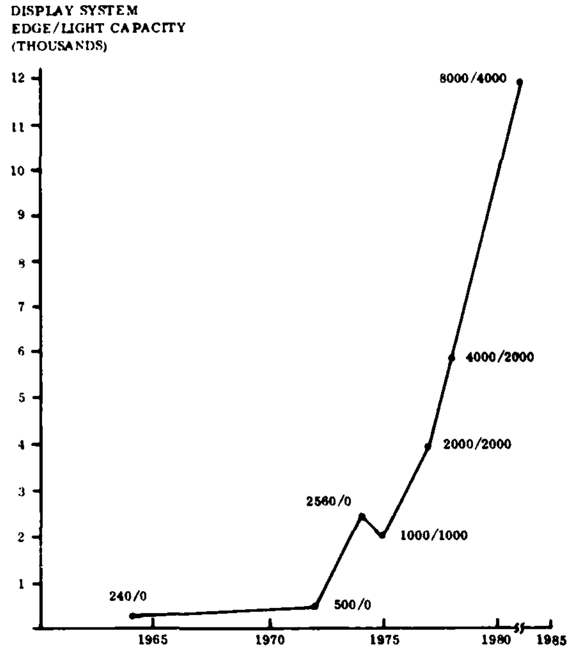


Figure 1. Growth in General Electric CIG System Display Capacities[1][3]

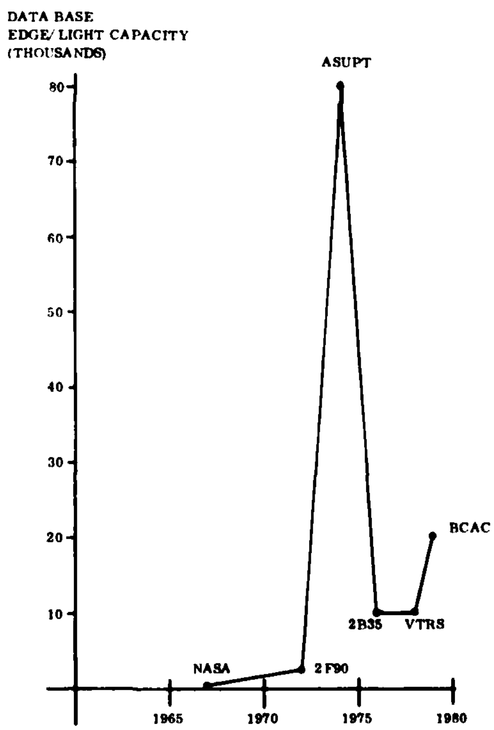


Figure 2. Growth in General Electric CIG Data Base Capacities[1][3]

magnitude using traditional manual techniques would require thousands of man years to produce at a cost of hundreds of millions of dollars to the product consumer.

## AUTOMATED DATA BASE GENERATION

In 1977 General Electric initiated the development of a computer program capable of generating CIG data bases with a minimum of human interaction. As shown in figure 3, inputs to this program are supplied by the Defense Mapping Agency Aerospace Center (DMAAC) in the form of digital terrain and culture data bases. DMAAC terrain files consist of elevation values sampled at regularly spaced intervals over the surface of the earth. The raw grid data is first blocked into geographic areas of manageable size, and a simplified subset is then obtained by detecting points of significance in the topological environment such as mountains, valleys, and ridge lines. Finally, a triangular faceted surface is fitted to the selected elevation values to force an approximation of rolling terrain.

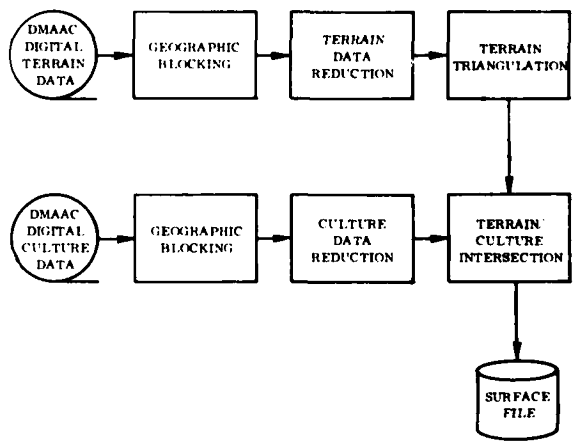


Figure 3. CIG Data Base Development Using DMAAC Digital Data

Planimetric features such as lakes, forests, and highways are also derived from DMAAC digital data bases. After blocking the raw input data in correspondence with the underlying terrain, DMAAC cultural features are processed to the degree of simplicity required by the CIG. The resulting culture data is then combined with the underlying triangulated terrain to form a single surface file.

### Data Base Enhancement

Although DMAAC data bases contain more information than the CIG can process, nevertheless, certain cultural features used by aircrews as navigational cues are often absent from the DMAAC cultural data bases. Therefore, the enhancement of the original DMAAC data using supplemental inputs such as Joint Operations Graphic (JOG) and U.S. Geological Survey (USGS) Quandrangle charts is a necessity.

General Electric presently employs a turnkey interactive graphics system to digitize data from JOG and USGS inputs. The digitized data from this process must be formatted to match DMAAC culture

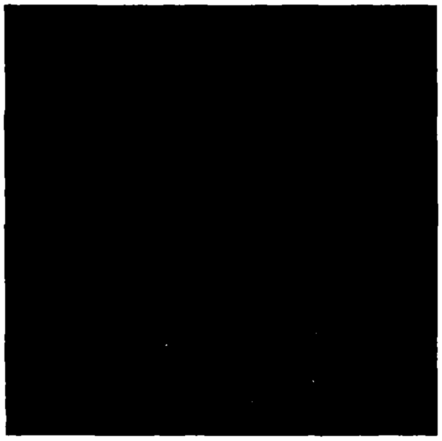

Figure 4. Sun Shaded DMAAC Terrain Elevation Data (Sun Angle = 45°)

Figure 5. Unprocessed DMAAC Culture Data (Surface Material Categories are Color Encoded)

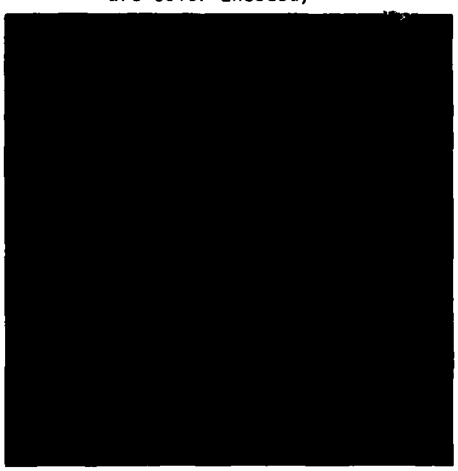

Figure 6. DMAAC - JOG Data from Manual Digitization (Roads, Railroads, and Waterways)

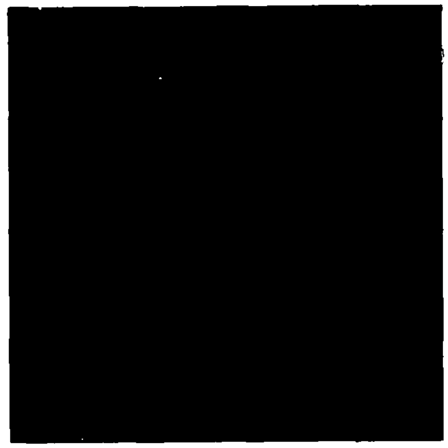

Figure 7. DMAAC Culture Data Enhanced with Manually Digitized JOG Data

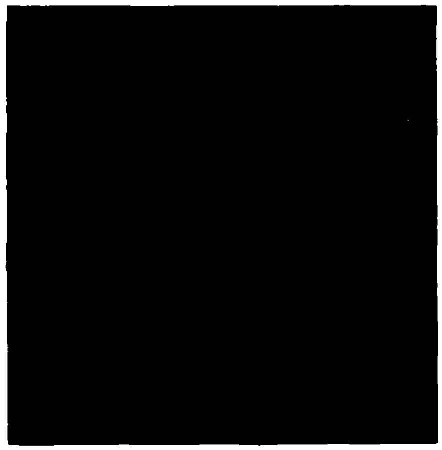

Figure 8. Enhanced DMAAC Culture Data Merged with DMAAC Terrain Elevation Data

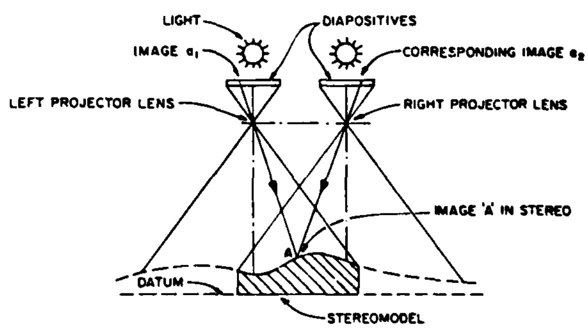


Figure 9. Generation of Three Dimensional Image from Stereopairs

file specifications, and the two files must be merged to form a single input to the automated data base generation program. Figures 4 through 8 illustrate the output of various steps of the culture enhancement process.

Traditional manual methods of data preparation are still required as a final step in the data base generation process. In addition to certain planimetric features not contained in DMAAC or supplemental data, models such as buildings, dams, bridges, and aircraft are painstakingly drafted and positioned in the final CIG data base. This final step is responsible for a large portion of data base development costs.

## FUTURE DIRECTIONS IN AUTOMATION

Manual enhancement of CIG data bases necessitated by Defense Mapping Agency data deficiencies is the limiting factor in total automation of the CIG data base development process. A joint effort of commercial and government agencies might someday lead to the production of a single source data base containing sufficient detail for all CIG visual data bases. In the meantime, at least two possibilities exist for the improvement of CIG data base quality which may also lead to lower system costs.

### Automatic Digitization

Cultural enhancement of CIG visual data bases involves the extraction of planimetric data from various maps, charts, and photographs using manual digitization methods, and the human operator must make decisions regarding the relative importance of features that are candidates for inclusion in the final data base. The lack of selection criteria, combined with errors arising from eye-hand coordination and operator fatigue, make manual digitization an inherently error prone and costly process.

Alternatives to manual digitization have been of interest to cartographers for many years, and devices such as facsimile and Brush recorders are routinely used in the preparation of maps and charts. Unfortunately, these products are usually designed to generate raster-formatted data which is incompatible with the vector-formatted data required by most CIG systems. Also, facsimile and Brush devices are extremely slow, and in general, the data output from these systems is too dense for use in flight simulation data bases. Recently, Boyle reported the development of an automatic digitization system using a flying spot scan of map separations.[4] This device is of potential value to CIG data base development systems by virtue of the vector-formatted output generated by the product, and the high speed with which data is captured. Furthermore, the use of map separations lends itself to the segregation of cultural data into logical groups such as water, forests, and highways for enhancement of DMA digital data bases.

### Stereometric Photography

Photogrammetry is the science of detecting information about physical objects by recording, measuring, and interpreting photographic images. As with automatic digitization, photogrammetry has been used for some time by government and commercial cartographers for the preparation of maps and charts. Metric photogrammetry involves the processing of overlapped photographs known as stereopairs to extract accurate three dimensional information about real world objects. The use of translucent positives, or diapositives, to form a three dimensional image is illustrated in figure 9.

The potential application of stereometric photography to CIG data base development was demonstrated recently for the Naval Training Equipment Center in Orlando, Florida. In this experiment, a Russian ship was digitized from stereophotographs taken of a scale model using close range camera equipment. As shown in the calligraphic plot in figure 10, the 350 polygon feature contains more than sufficient detail to be very effective in a CIG visual simulation, and furthermore, the feature was prepared in just two days using photogrammetric methods. The preparation of a similar feature utilizing traditional CIG data base development techniques would consume several months of effort.

## CONCLUSION

Visual scenarios now demanded of CIG flight simulators have forced the re-evaluation of traditional data base creation methods. General Electric has undertaken the automation of the data base generation process, and is committed to providing low cost simulators that will meet future consumer requirements. It is evident that government sponsored research should be aimed at the acquisition of high technology CIG data base generation techniques, such as metric photogrammetry and automatic scan digitization, which will lead to lower costs in future CIG systems.

## ABOUT THE AUTHORS

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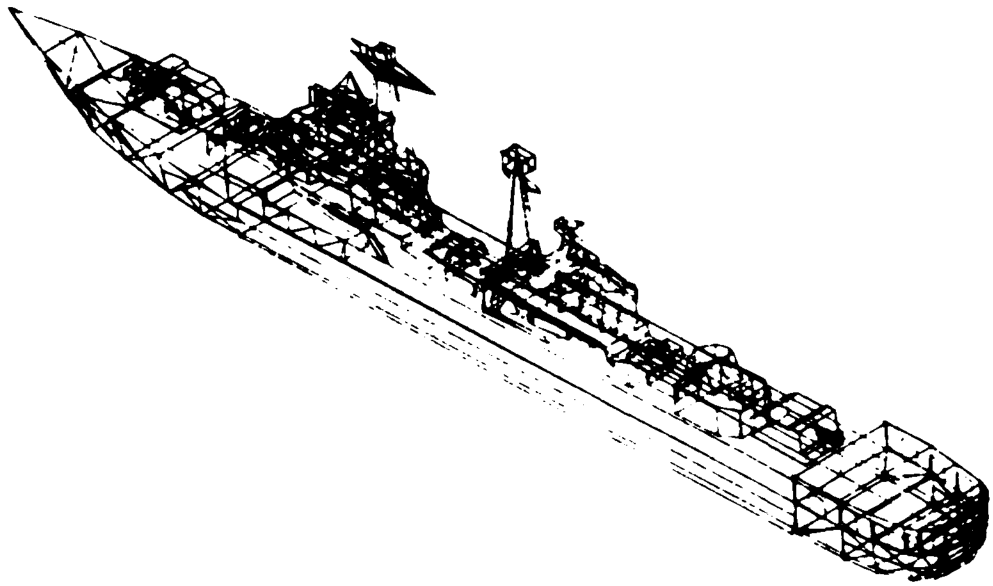
(4) Ray Boyle; "Scan Digitization and Drafting", Technical Papers of ACSM 40th Annual Meeting March 9 - 14, 1980 pp 136-142.



FRONT ROTATED

USING P1 NUMBER SELECTED 0 VISIBLE BIN 5
ON LEVELS 1 SAVED POINTS 0
EDIT LEVELS ALL REF LEVELS NONE
GRID 0 500 0 500 0 500 OFF 0 000 0 000 0 000
VUE CENTER. 3.071 1.407 0.127 WIDTH 3.500

Figure 10. Russian Ship Digitized from Stereometric Photographs
(Computer Systems Laboratory, NTEC, Orlando, Florida)

# EFFECTIVE ANTIALIASING OF COMPUTER GENERATED IMAGES

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## ABSTRACT

Aliasing in computer generated images produces artifacts which degrade training effectiveness. A rigorous implementation of low-pass filtering required to prevent aliasing requires computation too extensive to be incorporated into real-time computer image generation (CIG) systems. As a result, current CIG systems employ poor approximations to proper filtering, and aliasing still occurs.

This paper discusses the theory of image filtering and demonstrate a new real-time antialiazing technique developed from the theory. The new technique represents a much closer approximation to the rigorous solution and therefore produces images of much higher quality than current real-time techniques. At the same time it requires less computation.

## INTRODUCTION

Computer Image Generation systems represent a continuously varying image by limited sampling in both time and space. The dynamic image is represented as a sequence of static images or frames sampled in time at a rate between 30 and 60 frames per second. Each frame is represented by a finite number of spatially sampled picture elements or pixels generally arranged in a raster format with equal spacing. The Nyquist Sampling Theorem states that for any sampled signal any frequency greater than one half the sampling frequency will not be properly represented. The result is called aliasing because the under-sampled frequency components appear as different lower frequencies. Aliasing is a critical problem in CIG displays for training because it produces artifacts which are distracting and confusing to the trainee. Temporal aliasing occurs when the dynamic image changes significantly between sampled frames. Spatial aliasing occurs when any frame contains spatial frequencies greater than one half the spatial sampling frequency. In general, temporal aliasing occurs only during extreme vehicle maneuvers such as high speed rotation. Spatial aliasing, however, occurs in every frame containing high frequency information, such as that inherent in well-defined boundaries between surfaces. In addition, spatial aliasing anomalies are aggravated by dynamic presentation of the image sequence because each successive image is sampled slightly differently. As a result crawling, jumping and scintillation effects are produced at surface boundaries. Because the eye is so sensitive to dynamic changes, the temporal effects of spatial aliasing are extremely distracting and therefore degrade the training effectiveness of the CIG system. At the present time, therefore, spatial aliasing is by far the more critical problem to be solved to improve image quality. Consequently, we have concentrated our study on developing an effective technique for spatial antialiasing.

In seeking a solution to the spatial antialiasing problem, we must consider the frequency content of the images we will be generating and be careful to sample at a frequency at least twice that of the highest frequency in a given image. However, since sharp surface boundaries and corners, which contain infinite frequency components, are common, any finite sampling of the unfiltered image will produce aliasing. Constrained by a system with finite sampling, the ideal solution is to prefilter the image before sampling to remove all frequencies higher than half the sampling frequency. This can be done in two ways. First, the Fourier transform of the image can be computed and multiplied by the frequency domain transfer function of the appropriate low-pass filter. The inverse transform of the product will produce the filtered image. Alternatively, we could perform the equivalent operation in the spatial domain by convolving the image with the impulse response of the low-pass filter. A rigorous implementation of this convolution requires the integration of weighted intensity over the entire image for each pixel. Either of these techniques requires extremely involved mathematics to process complex surface boundaries. In addition, the immense computation load required is prohibitive.

Because of these problems, current CIG systems have retreated from proper image prefiltering to a variety of compromises which fail to reduce aliasing to an acceptable level. At the same time these compromises have added an undesirable amount of computation to achieve even a limited amount of antialiasing. In general, these compromise solutions attempt to adjust the intensity of any pixel which contains portions of more than one surface. The intensity of the pixel is represented by an average of the intensities of all surfaces within the pixel, each weighted by the fraction of the pixel area that it covers. Although seemingly straightforward, this approach is very costly in computation since the determination of subpixel areas is time-consuming even for straight edge boundaries. To simplify the computation some systems use an approximation, subdividing the pixel into an nxn array of subpixels for which the quantized image is generated and averaged for the total pixel. The problems of this technique are readily apparent. First, the computation load for an antialiased pixel is increased by a factor of $n^2$ (with n as high as 8). Second, a quantization problem still exists with the potential for producing distracting jumps in intensity in a dynamic image. Finally, even an exact, continuous area weighting does not satisfy the sampling theorem filtering requirement, so that aliasing can not be properly suppressed. In brief, current techniques provide too little antialiasing at too great a cost.

## EFFECTIVE ANTIALIASING

### The Ideal Solution

The theoretically correct solution to the aliasing problem is to filter the image before sampling. The frequency domain transfer function of the ideal presampling filter, $H(\omega_x,\omega_y)$ is shown in Fig. 1 (the sample spacing is assumed to be 1 in the x and y directions). The impulse response of this filter is:

$$h(x,y) = \frac{\sin(\pi x)}{\pi x} \cdot \frac{\sin(\pi y)}{\pi x} \quad -\infty \le x,y \le \infty \tag{1}$$

and the filtered image $F_F(x,y)$ is this convolved with the original image $F(x,y)$:

$$F_F(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x-R,y-S)F(R,S)\,dR\,dS \tag{2}$$

Direct evaluation of this integral for each sample is computationally very costly. It is desirable to find some approximations to this integral which give suitable results without a heavy computational burden.

### Approximating the Ideal Solution

Our goal is to develop a satisfactory approximation to the convolution in Eq (2) while minimizing the computation required. There are two important problems that we must solve. First, we must find a way to perform the convolution before sampling. Second, we must drastically reduce the number and complexity of the calculations.

For an image represented by a set of surfaces and their boundaries high spatial frequencies will occur only at abrupt changes in intensity. Such changes occur at the surface boundaries; regions within the boundaries will have low spatial frequencies and, therefore, will require no antialiasing. This implies that antialiasing can be limited to image regions near boundaries. Thus we can significantly reduce the computation of Eq (2) by restricting it to only a fraction of the image points.

We must further limit the computation by placing finite limits on the integral in Eq (2). We will do this by approximating the impulse response, Eq (1), by a weighting function with a finite domain. This domain, which we will call a sampling region, must cover a distance of at least two sampling periods in x and y for acceptable filtering. Restricting the calculation of the convolution not only reduces the computation load dramatically, but also allows us to make two more simplifications within each sampling region. First, within each sampling region, we will approximate all boundaries as straight lines. Second, we will assume surface intensity to be constant within the sampling region. With these approximations Eq (2) reduces to

$$F_F(x,y) = \sum_{i=1}^{N} I_i \iint_{R_i} h'(x,y)\,dx\,dy \tag{3}$$

for N surfaces visible within the sampling region R, with the $i^{th}$ surface visible over a region $R_i$ so that $\sum_{i=1}^{N} R_i = R$. The function $h'(x,y)$ is the weighting function approximation to $h(x,y)$.

For two surfaces separated by a single boundary, Eq (3) becomes

$$F_F(x,y) = I_1 \iint_{R_1} h'(x,y)\,dx\,dy + I_2 \iint_{R-R_1} h'(x,y)\,dx\,dy \tag{4}$$

We have now reduced the convolution to a form in which the integration is dependent only on the region of integration. In Eq (4) the regions of integration are determined by the location of the boundary. We have developed a technique to evaluate the integral of our weighting function explicitly as a function of a single continuous measure, $\ell$, of boundary position within the sampling region. This enables us to express the contribution of surface 1 to the filtered intensity of a sampling region as

$$F_{F_1}(x,y) = I_1 W(\ell) \tag{5}$$

where $W(\ell)$ is a new weighting function applied to the surface intensity and defined by

$$W(\ell) = \iint_{R_\ell} h'(x,y)\,dx\,dy \tag{6}$$

$W(\ell)$ is thus the volume defined under $h'(x,y)$ over $R_\ell$ and can be normalized to a maximum of one. $W(\ell)$ will equal zero when the surface lies outside the sampling region, will equal one when the surface covers the region and will vary continuously and nonlinearly as the boundary moves across the region. Since the total volume under $h'(x,y)$ over R will be normalized to one, Eq (4) can be written as

$$F_F(x,y) = I_1 W(\ell) + I_2(1-W(\ell)) \tag{7}$$

Equation (7) represents a manageable approximation of the ideal filtering defined by Eq (2). We have achieved a tremendous reduction in computation by restricting filtering to image points near boundaries, approximating the impulse response by a bounded weighting function, linearizing the boundary and assuming constant intensity within a sampling region, and devising a means of representing surface intensity weighting as a function of boundary position in the sampling region. In addition to its computational efficiency, this technique has the important feature of approximating the ideal filtering on the unsampled image. Because the filtering operation depends on a single continuous measure of boundary position, it will not introduce any quantization effect that could produce distracting jumps in intensity in a dynamic image.

## Demonstration of Results

We demonstrated the effectiveness of our antialiasing technique on extreme cases where aliasing is severe -- thin bright surfaces on a dark background. We defined surfaces with width equal to one pixel spacing using both linear and curved boundaries. The surface intensity was assigned the maximum value (1) and the background was assigned the minimum value (zero). Because each surface was so thin, in general two boundaries passed through a given sampling region. Accordingly, we modified Eq (7) to represent the contribution of the surface between the boundaries

$$F_F(x,y) = I_1(W(\ell_1) + W(\ell_2)-1) + I_2(2-W(\ell_1)-W(\ell_2))$$

$$= W(\ell_1) + W(\ell_2)-1$$

since $I_1 = 1$ and $I_2 = 0$.

To provide a benchmark, we used a current technique of area-weighted intensity as approximated by the n x n subpixel array. Since no improvement in image quality was perceivable for n greater than 8, we used this value as representative of exact area-weighting.

To demonstrate aliasing clearly we generated a 128-pixel-wide image of three thin surfaces with linear bounds at small angles to the scan lines. Figure 2 shows the unfiltered image with and without zoom-central enlargement by our scan converter. Antialiasing using the n x n subpixel array technique for values of n ranging from 2 to 8 is shown in Fig. 3a, b and c. Although considerable smoothing is apparent, some aliasing is still evident in the variation in intensity in the two lower lines. This residual aliasing holds the potential for distracting edge crawling in a dynamic display.

Figure 3d shows the same image antialiased by our technique. Since no variation in intensity is perceivable along any of the lines, and since filtered intensity at any pixel is a continuous function of boundary position, no dynamic discontinuities will be produced as the boundary moves in the image.

To demonstrate the behavior of our technique on surfaces with curved boundaries, we generated a test image of seven elliptical surfaces of 1 pixel width. Figure 4 shows the unfiltered image with and without enlargement. Figure 5a, b and c shows the image smoothed by the nxn subpixel technique for values of n ranging from 2 to 8. Evidence of aliasing is still present. Figure 5d shows the image after filtering with our technique. All perceivable aliasing has been removed.

## CONCLUSION

Despite the assumptions and approximations we used to make our technique computationally efficient, it performs antialiasing in a manner far superior to the area-weighted intensity technique because our technique represents a much better approximation to ideal filtering. First, it uses nonuniform weighting of intensity, and second, it applies the weighting over a larger region. To demonstrate the importance of each of these factors, we generated a test image of 21 concentric circles each 1 pixel wide. Figure 6a shows the unfiltered image. When uniform weighting is applied over two sampling periods (Fig. 6b), the region is large enough but the weighting is improper. Figure 6c shows the result of applying nonuniform weighting over a region covering only one sampling period. Figure 6d shows the result of applying uniform weighting over one sampling period, equivalent to area-weighted intensity in which both weighting and region size are improper. Effective antialiasing using nonuniform weighting over two sampling periods is shown in Fig. 6e.

The success of our technique is due to the fact that it is based on proper filtering before sampling. Because it uses a continuous measure of boundary position it eliminates the potential for distracting jumps in intensity in a dynamic image. The technique can be extended to antialias surfaces with multiple boundaries, such as small objects, by combining the position information of each boundary. Since each position is measured continuously, the combined weighting of surface intensity will vary without discontinuity.

We have demonstrated our technique on images including boundaries composed of lines or second-order curves. However, curves of any order can be handled as long as the equation of the boundary is known analytically.

Finally, the effectiveness of our technique is achieved at a low computational cost. The intensity weighting function depends on a single measurement of boundary position and involves a simple computation or table lookup. In the test images generated our technique took less computation time than the n x n subpixel array technique with n = 2.


## ACKNOWLEDGEMENT

The research described in this paper was sponsored by the Air Force Human Resources Laboratory (AFHRL) under contract F33615-79-C0029. The authors are grateful to Mr. William Foley and Capt. Michael Ingalls for the insight they provided into the problem of aliasing.


## ABOUT THE AUTHORS


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Edwin P. Berlin, Jr., BSEE, Massachusetts Institute of Technology, designs high-throughput computers for Grumman Aerospace Corporation. He holds a patent on a three-dimensional display device and has another pending.

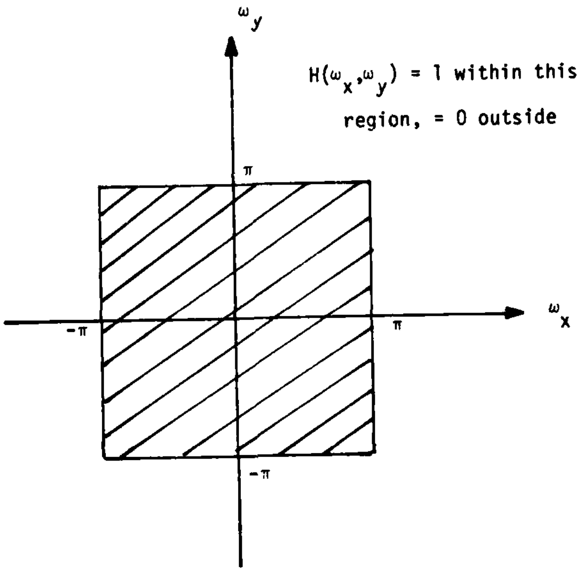
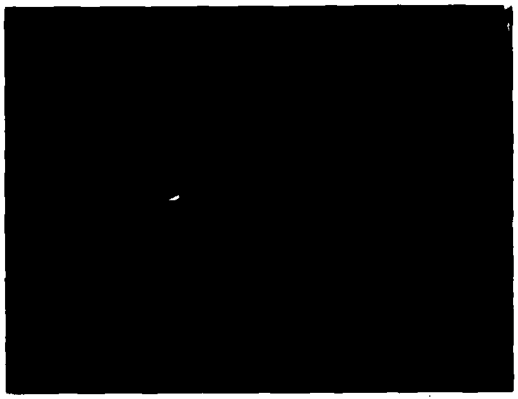
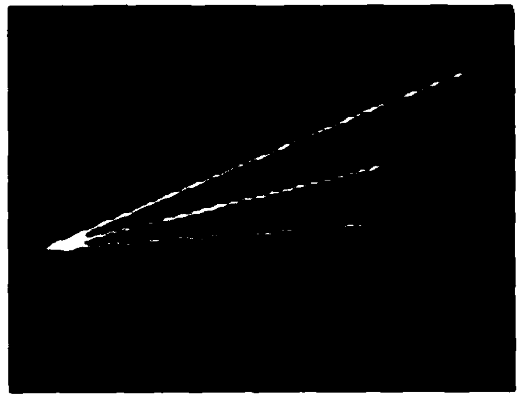



Fig. 1 Frequency Domain Transfer Function of Ideal Presampling Filter

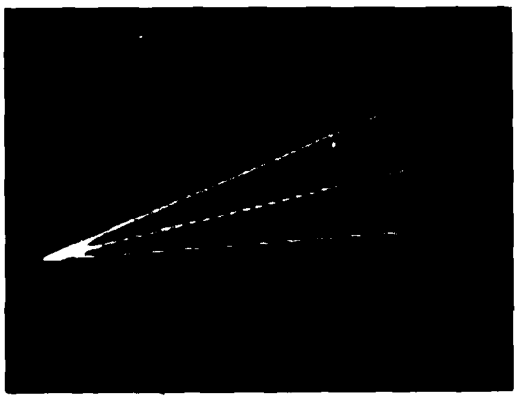


(a) Normal Size Image on 512 Pixel Wide Display

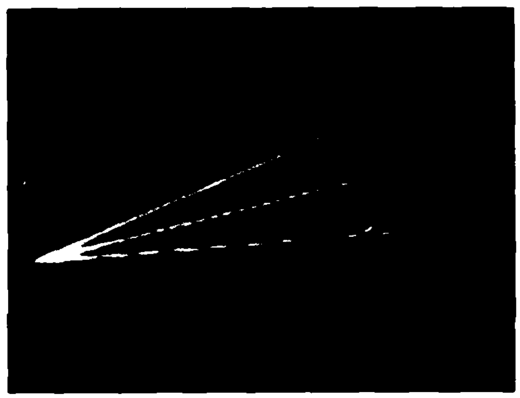


(b) Same Image Enlarged to Show Aliasing More Clearly

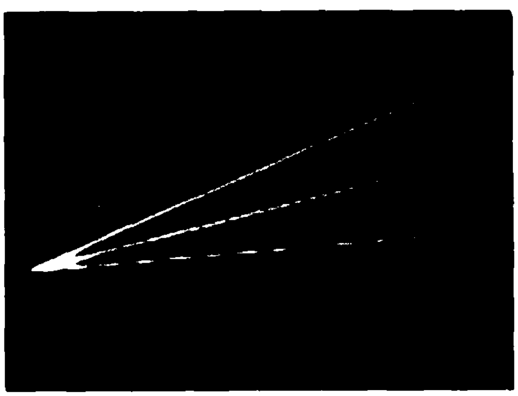
Fig. 2 Unfiltered Image of Thin Surfaces with Linear Boundaries



(a) 2 x 2 Subpixel Array



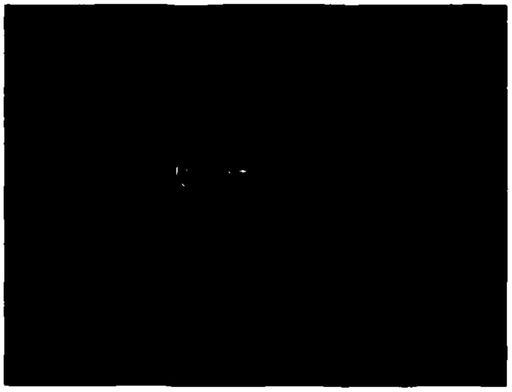
(b) 4 x 4 Subpixel Array



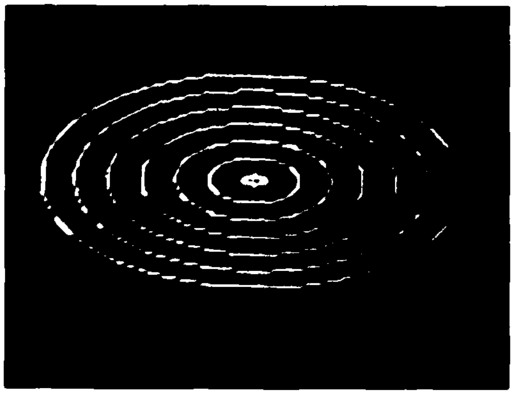
(c) 8 x 8 Subpixel Array

(d) Nonuniform Weighting Over Two Sampling Periods

Fig. 3 Antialiasing of Linear Boundary Image

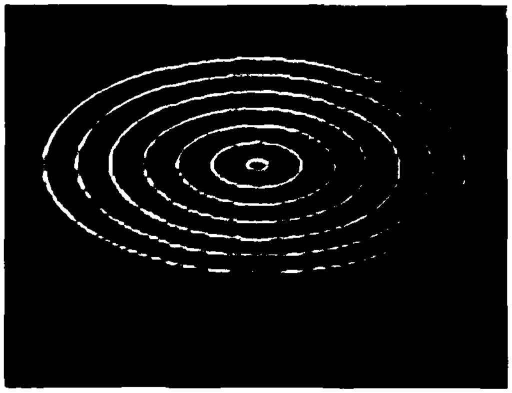


(a) Normal Size Image on a 512 Pixel Wide Display

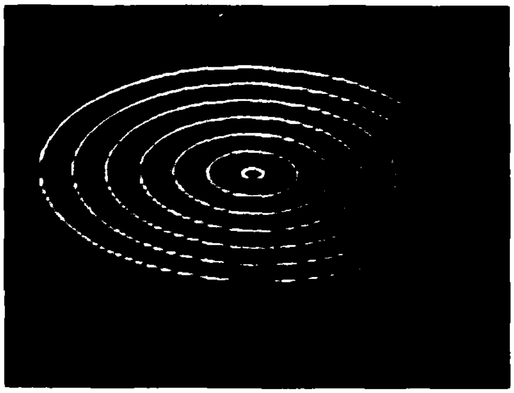


(b) Same Image Enlarged to Show Aliasing More Clearly

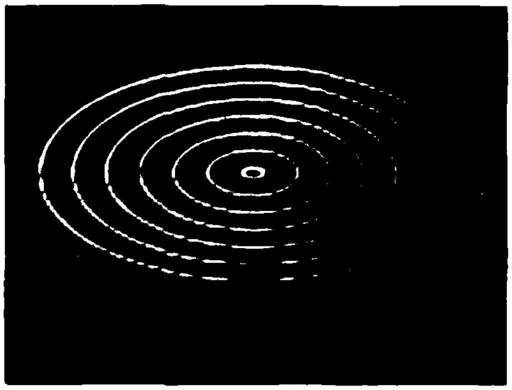
Fig. 4 Unfiltered Image of Thin Surfaces with Curved Boundaries



(a) 2 x 2 Subpixel Array



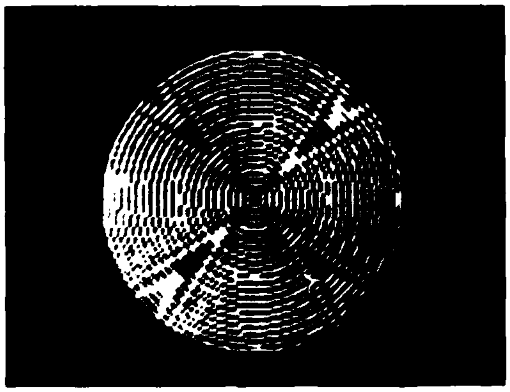
(b) 4 x 4 Subpixel Array



(c) 8 x 8 Subpixel Array

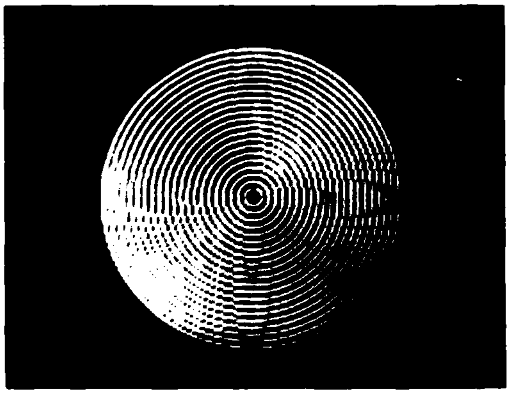
(d) Nonuniform Weighting Over Two Sampling Periods

Fig. 5 Antialiasing of Curved Boundary Image

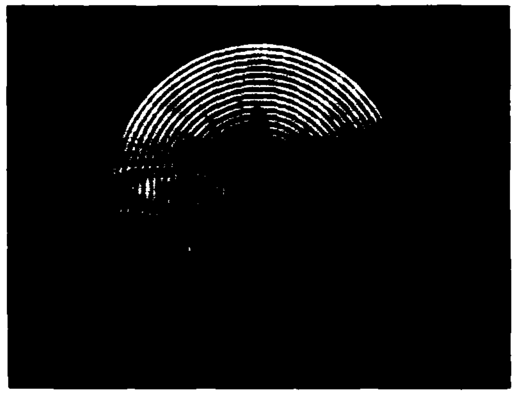


(a) Unfiltered Image

(b) Uniform Weighting Over Two Sampling Periods



(c) Nonuniform Weighting Over One Sampling Period



(d) Uniform Weighting Over One Sampling Period

(e) Nonuniform Weighting Over Two Sampling Periods

Fig. 6 Effect of Weighting Distribution and Region on Antialiasing of 21 Concentric Circles

# DISTORTION CORRECTION IN COMPUTER-IMAGE GENERATION-BASED WIDE ANGLE VISUAL DISPLAY SYSTEMS

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## ABSTRACT

Wide angle visual display systems used in flight simulation systems often exhibit distortion due to the display geometry and/or optics. Distortion correction in the image generator permits the use of a wide variety of display systems with the assurance that the correct perspective of the environment is always presented to the viewer. The paper will address the definitions of geometric and optical distortion followed by a discussion of some parameters relating to Computer Image Generation (CIG) and display system performance. Several kinds of displays including domes, on-or-off axis infinity systems, will be considered, together with the image projection devices used in these displays, including unshapeable light valve projectors with f-tan θ, f-θ, or anamorphic lenses, laser displays, or dynamically changing projectors. Some discussion of the distortion correction implemented on the Aviation Wide Angle Visual System (AWAVS) and Visual Technology Research Simulator's (VTRS) two flight simulators CTOL and VTOL at the Naval Training Equipment Center (NTEC), Orlando, Florida will be presented.

## INTRODUCTION

An inherent problem that confronts wide angle visual systems is distortion. The dominant contributors to distortion in systems of this type are the image generator and the display system. Some examples would be a Camera Model Image Generator, a Dome Display System, and an Off-Axis Infinity Display. In the past, distortion compensation for wide angle systems has been by camera raster shaping, display raster shaping, and by purely optical means [1], [2], [3]. Until now, Wide Angle Visual Systems employing Computer Image Generators have had to rely on the display to totally compensate for the distortion. This has limited the use of available display devices not before considered viable for wide angle applications. Thus the advent of CIG distortion correction will make these and future display technologies available.

## OBJECTIVES

It is apparent that wide field of view, visual simulation is one of simulation's most critical deficiencies [4]. Since Computer Image Generation has established itself as the prime source for wide field of view systems, the display is now the major obstacle facing systems of this type. Distortion and methods of correction have compounded this problem by limiting the number of display types and configurations that can be used with a CIG system. This being the case, one could conclude that the CIG must play a more integral role in the total visual system; that is, take advantage of its flexibility to eliminate the display system's distortion.

The Visual Training Research Simulator (VTRS) at NTEC made one of its primary goals the investigation and implementation of CIG comprehensive distortion correction. This correction was to be applied to those distortions encountered in dome type displays. The objectives were to apply this correction to a variety of display types and configurations. This included light valves with anamorphic f-θ lenses, symmetric f-θ lenses, f-tan θ lenses and the geometric distortions that resulted from a particular display configuration. Additional objectives were to demonstrate channel matching between two light valve projectors, with f-θ lenses, and demonstrate real-time dynamic correction. This would be required for a variable area of interest inset.

The CIG comprehensive distortion correction implemented was required to be flexible enough to compensate for any type or form of distortion.

### Distortion in Dome Displays

The dome display offers versatility in the mechanical layout of a flight simulator and will often aid the design concept in the areas of safety and reliability while yielding a wide field of view with moderate-to-good resolution, with a minimum of display channels. Dome displays, however, suffer from distortion arising from two causes. Geometric distortion is a result of the viewpoint and projection point not coinciding; therefore, images of straight lines from the projector are seen to be curved at the viewpoint. Another source of distortion is the projector optics. In a system with CIG input, the view window (and raster definition) is f-tan θ, and hence even a pure f-θ lens would yield distortion of the image. The combined result of these two distortions is asymmetrical, and is not readily corrected by simple optical methods.

## Types of Distortion

Geometric distortion in dome systems arises from two causes: dome curvature and the displacement of the projection system from the viewpoint. Interestingly enough, the first would not cause distortion if the latter were not the case. Since the projector lens cannot be placed at the eyepoint, the image of a straight line from the projection optics on the dome will look curved when seen from the viewpoint. There will also be a keystone effect similar to that given by an overhead projector whose optical axis is tilted. Figure 1 shows schematically the problem of geometric distortion.

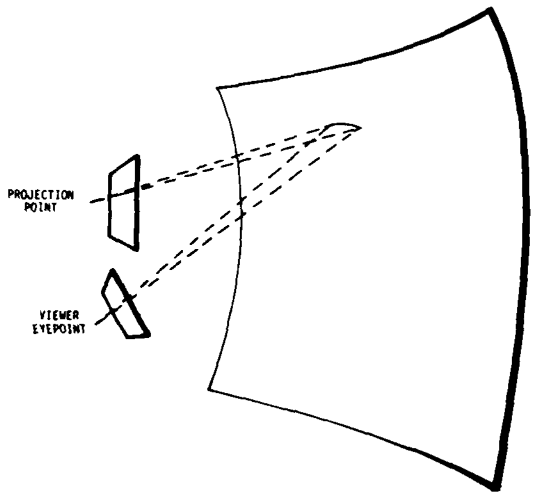



Figure 1. Geometric Distortion

Optical distortion is characterized by departure of a lens mapping from f tan θ behavior. In this discussion we shall assume that the depth of focus is infinite, i.e., the lens pupil is infinitesimal. An f tan θ lens maps according to the general rule that the image height from the optical axis to the image point, is proportional to the object height (i.e., the distance from the optical axis to the object point). A schematic representation is given in figure 2. A system with no distortion results in the following equality;

$$\overline{P_1'O'}/\overline{P_1O} = \overline{P_{IE}'O'}/\overline{P_EO}.$$

A system departing from this expression yields distortion to the extent that $P'_E$ departs from $P'_{IE}$.

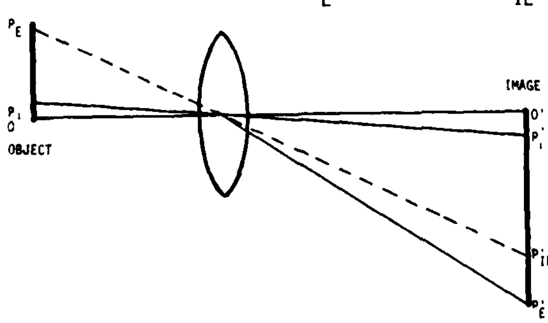



Figure 2. F-Tan-θ Lens with Distortion

Wide angle systems, such as that at VTRS, often use a lens with an f-θ mapping; that is, the angle from the optical axis to the image point is proportional to the object height. This type of lens is practical for such systems since it equalizes the angular resolution to the eye over the wide field. However, it is not compatible with CIG systems as they are currently defined, since they require a flat rectangular view window for edge definition. (A non-planar view window introduces the difficulty that edges in the environment project to a curve in the view window that is not a linear function of scan line and element number.) The projection of an fθ lens image onto a flat surface, shown in figure 3 has pincushion distortion.

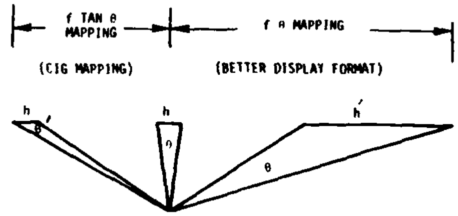



Figure 3. Flat Plane Projection of fθ and f Tan θ Lenses; Where θ' < θ

When we consider the view window definition and the way that a CIG system processes image data, we find that a wide angle f-θ lens system results in an artificial compression of the image near the center of the field of view and an artificial expansion of the image near the edge. The key to this effect can be seen by considering an example.

The general equation for determining the angle θ to a scan line L, if $L_m$ is the number of lines from the optical axis to the edge of the field $\theta_m$ is the angle to the edge, is given by $\theta = \tan^{-1}[L(\tan\theta_m)/L_m]$. As an example, suppose the half-field (the angle from the optical axis to the edge of the field) is 40° and over this half-field we have 400 raster lines. Suppose a face segment extends from line 300 to line 400 in the CIG view window. Then the angle that should be subtended by it is given by;

$$\tan^{-1}\left(\frac{400\tan 40°}{400}\right) - \tan^{-1}\left(\frac{300}{400}\tan 40°\right)$$

$$= 40° - 32.183° = 7.187°$$

However, if lines 300 to 400 are displayed through a projector with an fθ lens, lines subtend an angle of 10°. Hence the displayed image would be larger than it should be, i.e., there is an artificial magnification near the edge of the field. Now suppose a face segment extends from line 0 to line 100. The angle it should subtend is equal to $\tan^{-1}(1/4 \tan 40°) = 11.847°$, but again it would subtend an angle of only 10° when projected through the f-θ lens. Hence there is an artificial compression near the center of the field. Keep in mind that this image compression refers to the scene content and not to the display resolution.

The distortion seen on wide angle displays is a combination of the types of distortion given above, and is not symmetric, due to geometric distortion. In the past, simple optical methods have not been successful to correct this kind of distortion.

## CIG Distortion Correction

### The General Approach to Distortion Correction

The real-time distortion correction hardware for an edge-oriented CIG system essentially resides between Frames II and III of the system; where Frame II processes object and face data and generates edges, and Frame III determines the video entries for line-by-line raster scan.[5] [6] The basic function of the CIG distortion correction is to map vertices so that they will project to the right places relative to the viewer, and to compensate for curvature introduced by the system. Essentially the geometric and optical distortion is a view window problem and needs to be applied to the system for the purpose of defining new edges immediately after the edge definition is made. Exceptions to this characteristic are those aspects of CIG that are handled by incrementers in Frame III, namely texturing and horizon fading. To implement these features properly, one must perform a pixel-by-pixel mapping in Frame III while these functions are being performed.

### Mapping of Edges

The edge mapping required for distortion correction takes edges from the viewer raster and maps them to the projector raster. This involves a mapping from the viewer to the dome surface, followed by a mapping from the dome surface to the exit pupil of the projection lens, and followed in turn by a mapping to the projector raster. Two possible outputs to this mapping have been considered. One is to define the image of the edge as a second-order function of scan line and element number, that is $a_1 I^2 + a_2 J^2 + a_3 IJ + a_4 I + a_5 J + a_6 = 0$.

This would require the solution of six equations and six unknowns for each edge, in addition to mapping four additional points per edge. The other approach would be to segment each Frame II edge into enough pieces to ensure that the resulting image is linear to the viewer. This would require an increase in the edge capacity of Frame III and would also increase the edge burden per scan line approximately 10 percent. For an edge oriented CIG system
hardware required is less for the second (i.e., segmentation) approach, and hence that was chosen.

### Segmentation of Edges

The goal of the edge breakup is to segment the edge into enough pieces so that each piece, when mapped by the distortion correction map looks like a straight line on the projector raster to within a maximum allowed error $E_{max}$. The departure from linearity of the mapping of one of these segments is assumed to be a maximum at the midpoint of the edge. Hence we talk about the midpoint error E associated with representing this mapping as a segment. This is illustrated in figure 4. Here E is the distance from the mapping of the midpoint of the viewer's edge to the straight line segment shown in the projector raster. The maximum allowed midpoint error $E_{max}$ is decided by the designer, and off-line software determines how much an edge needs to be segmented to get E to within $E_{max}$. The segmentation factor depends on the edge position, its length, and its orientation.

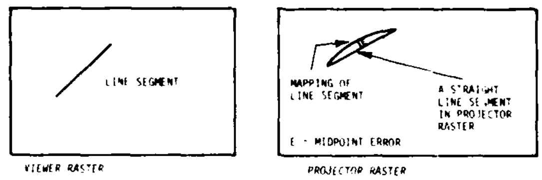


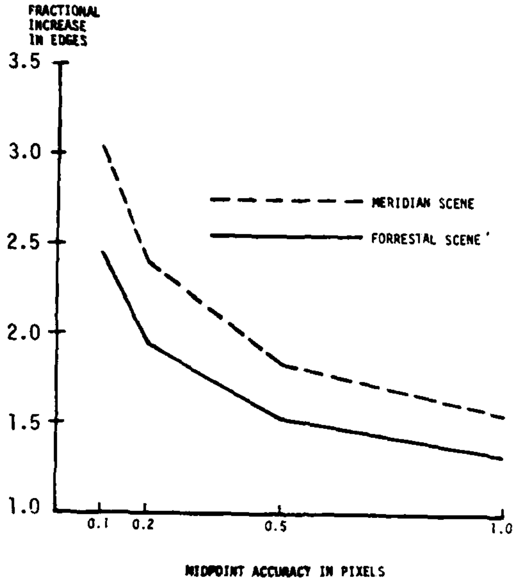

Figure 4. Definition of Midpoint Error

Once an edge is segmented, the output edges are mapped to the projector raster positions and are sent to Frame III.

A fundamental question concerning the impact of segmentation on a CGI system is the number of segments to be expected from a "typical" scene. A scene would usually consist mostly of short edges that need only be mapped, but not segmented, while some edges may need both. An edge data dump was taken from the CGI Frame II for several scenes, and this data was mapped and segmented sufficiently to yield a given "midpoint error" accuracy for the VTRS Conventional Carrier Take-Off and Landing Simulator, (CTOL) background and target lens systems. Plots of the fractional increase in edge burden (edges out/edges in) versus the midpoint error accuracy in number of pixels required are shown for the background lens in figure 5 and for the target lens in figure 6 for a pair of scenes (one scan with the USS Forrestal taking up half the field of view and one scene of the Meridian Mississippi airfield). Especially for the background lens, there is a quite significant increase in edges due to segmentation, even if the mapping accuracy is only one pixel.

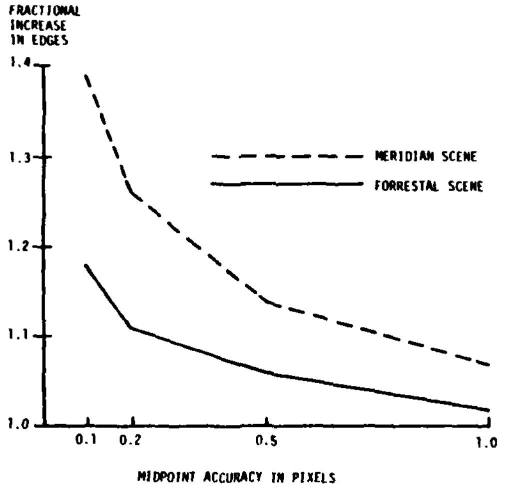
## RESULTS

Distortion correction has been applied to the VTRS CGI and display systems. In the VTOL system, the distortion correction has been simultaneously applied (real time) to two identical background channels, each with its own view window orientation, and with its 90° horizontal by 70° vertical fields of view (114° diagonal fields) using GE color light valve projectors and radially symmetric f-θ lenses. The layout of the dome, Lamps Mark III helicopter mockup cockpit, and optics is shown schematically in figures 7 and 8. The projector and optics is shown in figure 9. Of particular importance in this layout is the downward field of view critical for carrier deck landing training.




Increase in edge burden as a function of midpoint error.

Figure 5. Background Lens ($160^0 \times 80^0$ fθ Anamorphic)




Increase in edge burden as a function of midpoint error.

Figure 6. Target Lens ($55^0 \times 43^0$ max, f tan θ zoom from 1:1 to 10:1).

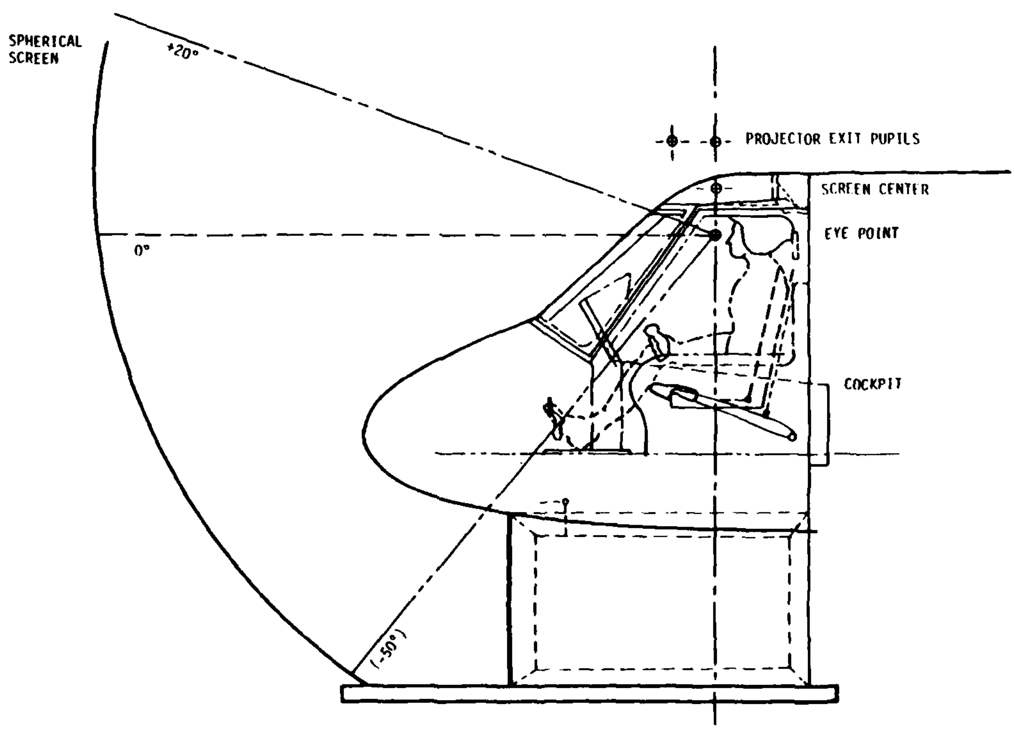



Figure 7. Elevation View of VTOL Cockpit Configuration

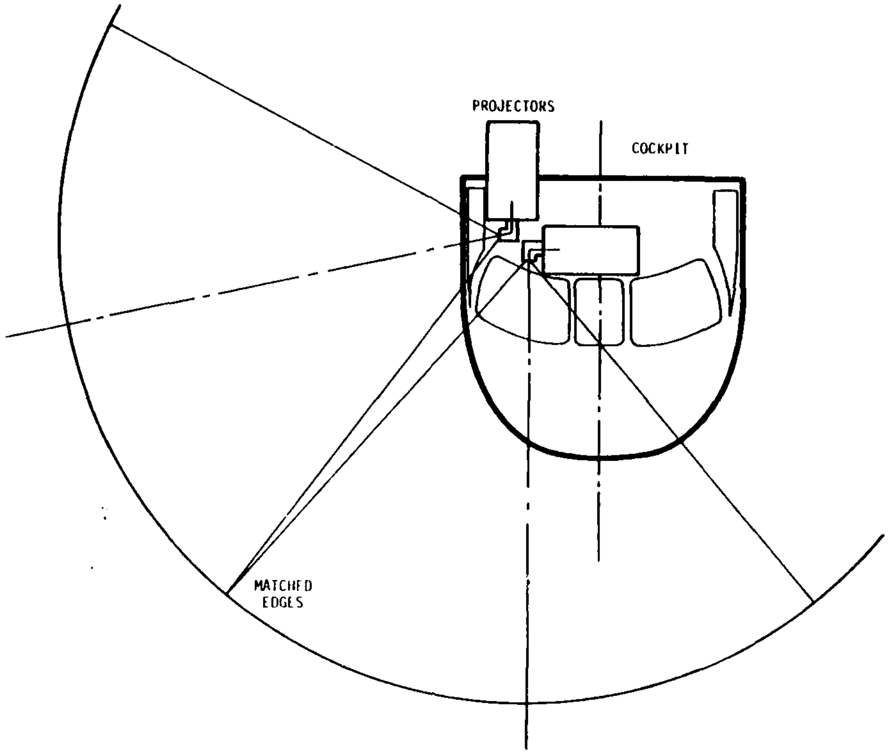



Figure 8. Plan View of VTOL Cockpit Configuration

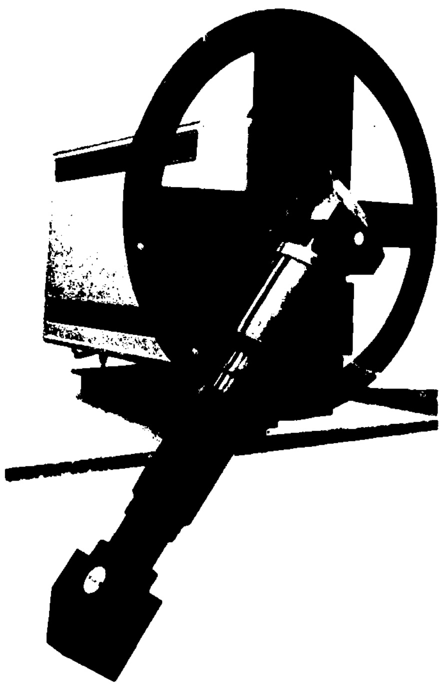


Figure 9. Projector and Optics Assembly

This mechanical configuration allows tremendous flexibility in regard to projection attitude. The lens can be rotated 360° in two axis; one of them is about the original optical axis of the light valve, and the other is the rotation of the projection head about the axis defined by the long leg of the lens assembly. A pechan prism is provided to compensate for any image roll introduced. This provides the ability to juxtapose many projectors resulting in a large continuous field of view.

In the CTOL system the distortion correction has been applied statically to a 160° × 80° background field of view, using a monochrome GE light valve projector and a wide angle f-θ anamorphic lens. A schematic layout of the optics, dome, and the T2C cockpit is shown in figure 10.

field prior to distortion correction.

## CONCLUSIONS

Thus far Comprehensive Distortion Correction (CDC) has been successfully applied to dome display systems with schlieren type light valves and projection lenses. The flexibility of CDC has made it attractive to other wide angle type display systems; for example laser displays, In line Infinity Optical Systems (ILIOS) and off axis infinity display systems.

Laser displays with their varying scanning techniques invariably introduce distortion. Some laser display systems require nonconventional image generator inputs that are required to compensate for the laser projector distortion (7). CDC can remedy this by offering the display designer the freedom to use a wide variety of scanning concepts that best suit a particular visual system. It must be noted that the level of CDC complexity is directly coupled to the scanning method. For example, distortion introduced by a typical raster scanning technique is more readily corrected than for one that requires an annular image input. A particular scanning method could impact the image generator and visual system in one or all the following ways: add a frame time delay, a need for output field buffers, the necessity for high speed digital to analog converters, or the number of displayed edges. These effects can be reduced or eliminated if trade-offs are exercised early in the display and image generator design.

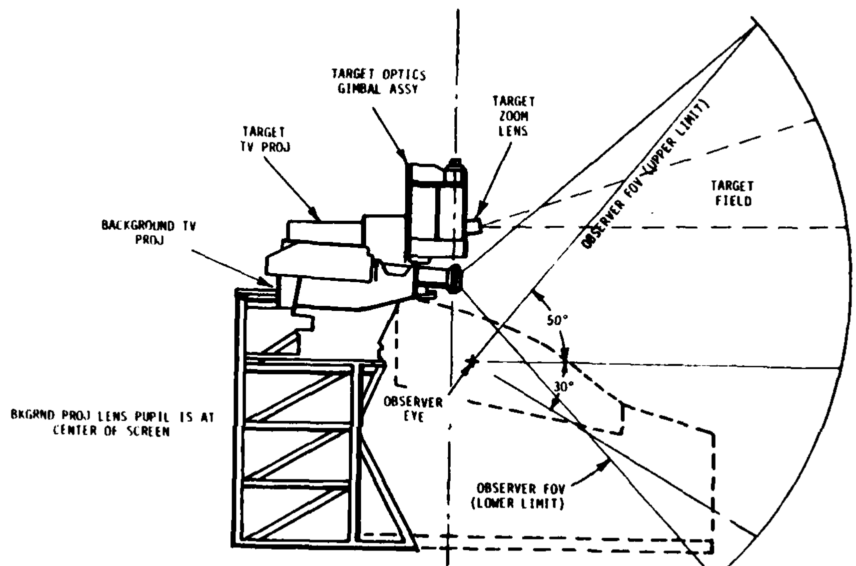



Figure 10. CTOL Cockpit Configuration

The real-time correction for the CTOL is now in progress for both the background and the target lens (the target lens is a moveable f-tan θ lens with zoom). The CIG transport delay, i.e., the time between a Frame 1 Operational Flight Trainer input and the display of that frame, was increased by a field during implementation of distortion correction, due to the necessity of retrofitting distortion correction to an existing system. A comprehensive CIG design incorporating distortion correction should eliminate this delay.

The real-time application of distortion correction at the present time includes edges, curved surface shading, and fading. Study efforts are currently defining the application with texturing, oversampling smoothing, and dynamic priority.

Photographs have been taken of displayed imagery in the CTOL system with and without distortion correction. A pair of such photos showing the U.S.S. Forrestal is given in figures 11 and 12. Inspection of these photos reveals the curvature introduced by distortion, and its correction. Also one can notice the artificial magnification of the carrier near the edge of the

CDC can offer ILIOS (8) a feature not before achieved with an image generator input, regardless of the display input i.e., CRT's, light valves, or lasers. This feature is to provide, to the observer, raster lines that subtend equal angles. Presently the Advanced Simulator for Pilot Training (ASPT) visual system displays the raster lines

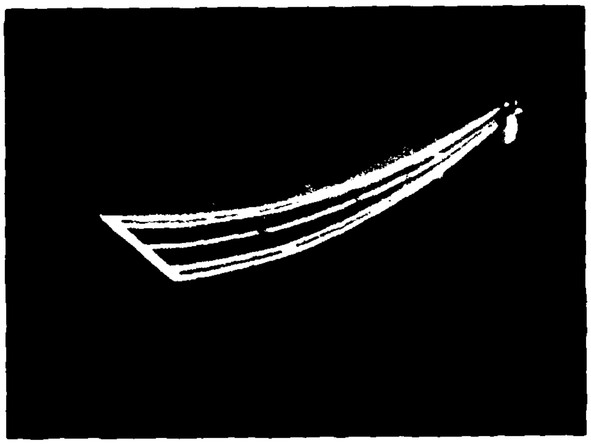


Figure 11. Scene of USS Forrestal Projected on Dome Exhibiting Anamorphic Distortion

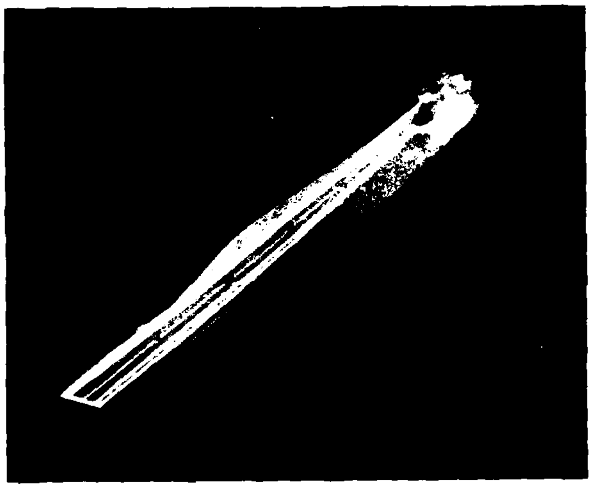


Figure 12. Same Scene as Figure 11 with Distortion Corrected

as the tangent of the angle. On ASPT, this results in higher angular resolution (approximately 1.5X) between raster lines at the extreme field ($\pm 45^o$) than in the center. This higher resolution area is wasted in the region of the total field of view of the optical system. This means that this region is only visible with head motion and not from the nominal eyepoint. However, with the raster distributed at equal angles, a *uniform resolution is obtained throughout the* ILIDS field of view and across channels. This also simplifies the display in that it relaxes the requirement for a higher resolution off axis than in the display center which is contrary to the way displays normally perform. CDC can simplify and improve the display design and performance in systems of this type, while applying the *same correction algorithm to each channel.*

CDC also can be applied to off axis infinity displays that enherently have asymmetric distortion characteristics that are normally compensated by optical means.

In summary, CDC provides the visual simulation community, with a necessary ingredient that will aid in the design of wide angle display systems. Since its conception three years ago, it has proven itself as a viable addition to the total visual system. With its feasibility clearly demonstrated at VTRS present and future, visual systems can take advantage of CDC in their display design.

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# COMPUTER GENERATION OF CURVILINEAR OBJECTS

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## ABSTRACT

This paper surveys alternative approaches to curvilinear object generation by computer. These alternative approaches are compared in terms of ease of generation of silhouettes of objects, ease of intensity computation, ease of texture generation, image quality, data base compactness and flexibility of modeling free-form curvilinear objects. The alternative approaches surveyed are planar surface approach, quadric surface approach and parametric surface approach. Other techniques within the class of parametric surfaces which appear to be promising but have not yet been tried are also discussed.

## INTRODUCTION

For digital presentation in support of flight simulation, it is frequently necessary to portray man-made or natural curvilinear objects such as water towers, oil storage tanks, bomb craters, silos, aircrafts and rolling terrain. In most existing real-time, computer-generated image (CGI) systems, these curvilinear objects are approximated by planar polygons. We will refer to this approach as the planar surface approach.

The extensive use of planar surface approach in existing real-time CGI systems is due to the ease of real-time implementation with this approach. However, there are two major shortcomings of this simple approach. The first shortcoming of planar surface approximation for curvilinear objects is that, while smooth shading restores smoothness to these objects, the silhouettes remain angular. The second shortcoming is that a great number of planar surfaces are required for good approximations of curvilinear objects, thus inflating the size of the data base.

It is these shortcomings of planar surface approach that have stimulated active research in search of alternative approaches. The alternative approaches known are mainly results of studies by universities doing research in computer graphics and by the training equipment industry. These alternative approaches can be divided into two classes of approaches, namely, parametric surface approach and quadric surface approach.

In the following sections we will survey known techniques of the three approaches for curvilinear object generation, namely, planar surface approach, quadric surface approach and parametric surface approach. Techniques within these three classes of approaches will be compared in terms of the following attributes:

1. Ease of generation of silhouettes of objects.

2. Ease of intensity computation within silhouettes of objects.

3. Ease of texture generation within silhouettes of objects.

4. Image quality.

5. Data base compactness.

6. Flexibility of modeling free-form curvilinear objects.

## COORDINATE SYSTEMS

For the coordinate systems used, let ($x_e$, $y_e$, $z_e$) denote coordinates in the environment (or earth) coordinate system; let ($x_p$, $y_p$, $z_p$) denote coordinates in the pilot's eye coordinate system. The pilot's eye coordinate system is such that the origin is at the pilot's eye; the $z_p$ axis is perpendicular to the image plane. The pilot's eye coordinate system and the "3-D screen" coordinate system ($x_s$, $y_s$, $z_s$) are related by a perspective transformation:

$$x_s = x_p/z_p$$

$$y_s = y_p/z_p$$

$$z_s = 1/z_p$$

This perspective transformation has the property that perspective projection (with the pilot's eye as the vantage point) of objects onto the image plane in the pilot's eye coordinate system is equivalent to orthographic (vantage point at infinity) projection of them onto the image plane in the "3-D screen" coordinate system (1). Therefore, $x_s$ and $y_s$ coordinates in the "3-D screen" coordinate system are the 2-D screen coordinates on the image plane. Notice that $z_s$ is the reciprocal of $z_p$, the Z-depth. Therefore, $z_s$ can be used directly for priority algorithms which employs depth comparisons.

## PARAMETRIC SURFACE APPROACH

Parametric surfaces are surfaces defined on two independent parameters most often denoted by u and v. The 2-D u-v space is also referred to as the parametric space. The two parameters are usually normalized to lie between 0 and 1. Thus, a normalized u-v space is a unit square. In the environment coordinate system, a general parametric surface is defined by three equations in u and v as follows:

$$x_e = f(u,v) \qquad [1]$$

$$y_e = g(u,v) \qquad [2]$$

$$z_e = h(u,v) \qquad [3]$$

where $0 \le u,\ v \le 1$.

The above equations define one "patch" of an object modeled with parametric surfaces. An object is usually modeled by piecing together many such patches. Normally, certain orders of continuity ($C^2$ continuity for curvature continuity, $C^1$ continuity for gradient continuity, and $C^0$ continuity for position continuity) are desired, both within patches and along patch boundaries, to give the desired degree of smoothness to the appearance of objects.

The complexity of the three functions, f, g and h, depends on the order of continuity desired. The functions f, g and h are, in general, nonlinear in u and v. It should be noted that when f, g and h are linear in u and v, the patch reduces to a planar surface.

In the following subsections we will discuss various types of parametric surfaces and the computations involved for their rendition.

## Bicubic Patches

Mathematical Background. Bicubic patches are those parametric surfaces in which the f, g and h functions in equations [1], [2] and [3] are bicubic in u and v. In the environment coordinate system, a bicubic patch is defined as follows:

$$x_e = UBX_eB^TV^T \quad [4]$$

$$y_e = UBY_eB^TV^T \quad [5]$$

$$z_e = UBZ_eB^TV^T \quad [6]$$

where $U = (u^3 \; u^2 \; u \; 1)$ and $V = (v^3 \; v^2 \; v \; 1)$ are row matrices; the superscript T indicates matrix transposition. $X_e$, $Y_e$ and $Z_e$ are 4x4 matrices defining the three coordinates of 16 "control points." B is a constant 4x4 matrix.

For the same surface, the type of control points will determine the constant B matrix to be used. Coons' control points consist of four corner position vectors of the patch, two tangent vectors (one in the direction u, the other in the direction v) and one "twist vector" in the four corners (2). This information usually does not provide an intuitive "feel" for the shape of the surface. Therefore, Coons' patch finds little use on interactive surface design. On the other hand, control points of Bezier (3) and B-spline (4) surfaces consist of 16 position vectors. Four of these 16 position vectors are the four corners of the patch and the other 12 position vectors, even though not on the patch itself, have the effect of attracting (like a magnet to a flexible metal sheet) the patch towards them. Bezier and B-spline patches therefore provide the intuitive feel for surface design. One advantage of a B-spline surface over a Bezier surface is that the effect of moving a control point of a B-spline surface is local while that of a Bezier surface is global.

Regardless of whether the control points are expressed in Coons, Bezier or B-spline form, they are of the same form as shown in equations [4], [5] and [6]. It can be shown that for a control point matrix in one form there exist transformations to compute an equivalent control point matrix in the other two forms. Rendering of bicubic patches will be discussed in terms of equations [4], [5] and [6]. The mathematics involved in rendering a true perspective view of bicubic patches will be described next. The two major steps in rendering a perspective view of an object are finding the object's silhouette and the surface normal at each point within the silhouette for intensity computation.

Because the control points are either position vectors or direction vectors, they can be spatially transformed to the pilot's eye coordinate system (rotation for direction vectors and translation and rotation for position vectors). Let the surface be expressed in the pilot's eye coordinate system as follows:

$$x_p = UBX_pB^TV^T = UMV^T \quad [7]$$

$$y_p = UBY_pB^TV^T = UNV^T \quad [8]$$

$$z_p = UBZ_pB^TV^T = ULV^T \quad [9]$$

where $M=BX_pB^T$, $N=BY_pB^T$, and $L=BZ_pB^T$.

Let the tangent plane to the surface at (u,v) be given by

$$a(u,v)x_p + b(u,v)y_p + c( \text{[illegible]} d(u,v)=0 \quad [10]$$

Therefore (a(u,v),b(u,v),c(u [illegible] is the surface normal vector (in the pilot's eye coordinates) at (u,v). Taking equation [10] through perspective transformation we have:

$$a(u,v)x_s + b(u,v)y_s + d(u,v)z_s + c(u,v)=0 \quad [11]$$

Therefore, the surface normal vector (in screen coordinates) at (u,v) is (a(u,v),b(u,v),d(u,v)). It can be shown that a(u,v), b(u,v), c(u,v) and d(u,v) are biquintic in u and v.

The surface normal vector in pilot's eye coordinates is used for intensity computation while that in screen coordinates is used for finding the silhouette of a patch discussed below.

Applying perspective transformation to equations [7], [8] and [9], we have

$$x_s = UMV^T/ULV^T \quad [12]$$

$$y_s = UNV^T/ULV^T \quad [13]$$

$$z_s = 1/ULV^T \quad [14]$$

In the screen coordinate system the space curves of the four boundary curves of the patch are given by substituting u=0, u=1, v=0 and v=1 in equations [12], [13] and [14]. These four boundary curves are therefore univariate rational cubics (rational cubic functions of one independent variable) in u or v. The plane curves of these four boundary curves on the screen are given by the x and y components of the corresponding space curve in the screen coordinate system.

In the planar surface approach, scan line intersections of a boundary edge are calculated incrementally. However, in the bicubic patch approach, in order to get the intersection of a particular boundary curve (say v=0) with scan line k, we first have to solve for u with the following cubic equation in u:

$$y_s = \frac{UN\ [0\ 0\ 0\ 1]^T}{UL\ [0\ 0\ 0\ 1]^T} = k \qquad [15]$$

The above equation can be rewritten as:

$$\frac{a_1u^3 + b_1u^2 + c_1u + d_1}{a_2u^3 + b_2u^2 + c_2u + d_2} = k \qquad [16]$$

Once u is obtained, $x_s$, a rational cubic equation in u, can be evaluated.

To obtain the surface normal at (u,0) for intensity computation, (u,0) is substituted into the parametric surface normal equations.

The four boundary curves of a patch do not completely define the silhouette of a patch. Other curves (known as silhouette curves), which are dynamically defined as a function of the viewing direction, are necessary to completely define the silhouette of a patch. This is illustrated in Figure 1.

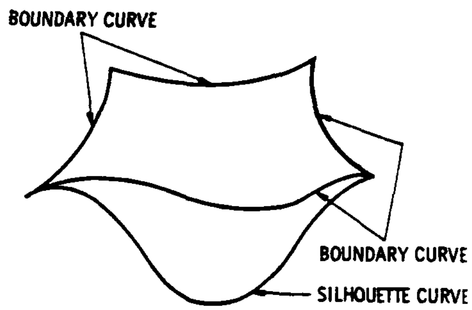


Figure 1

Boundary and Silhouette Curves Constitute the Silhouette of a Patch

The silhouette curve of a surface is defined mathematically as the locus of points on the surface which have a zero Z component of the normal vector in screen coordinates (i.e., d(u,v)=0). It is interesting to note that, from equations [10] and [11], requiring d(u,v)=0 is equivalent to requiring the constant term of the tangent plane in pilot's eye coordinates to be zero. In other words, the silhouette edge can also be defined as the locus of points on the surface which have a tangent plane in the pilot's eye coordinate system passing through the eye point.

The (u,v) for the intersection of a silhouette curve with scan line k is given by the solution of the following two bivariate polynomial equations (polynomial equations of two independent variables):

$$y_s = UNV^T/ULV^T = k \qquad [17]$$

$$d(u,v) = 0 \qquad [18]$$

The first equation is bicubic in u and v while the second is biquintic in u and v. For scan line intersections of a boundary curve, an equation with a single parameter is involved. However, for scan line intersections of a silhouette curve, two equations with two parameters are involved and, thus, the computations are much more expensive.

To obtain (u,v) for a picture element ($k_1$, $k_2$) on the patch not on silhouette or boundary curves, the following two bicubic equations have to be solved:

$$x_s = UMV^T/ULV^T = k_1 \qquad [19]$$

$$y_s = UNV^T/ULV^T = k_2 \qquad [20]$$

The (u,v) obtained is then substituted into the surface normal equations for intensity computation.

In the following sections we will examine various researchers' approximations to the rendition of true perspective view of bicubic patches in order to simplify the computations.

Catmull Algorithm (5). Catmull devised the first algorithm to render curvilinear objects modeled with bicubic patches. The algorithm is as follows: Each bicubic patch is recursively subdivided* into smaller subpatches until the image of each subpatch covers only one picture element. The screen coordinates $x_s$, $y_s$ and $z_s$ and the three components of the surface normal in pilot's eye coordinates a(u,v), b(u,v) and c(u,v) of the patch are evaluated and carried along with each subdivision. We will refer to the evaluation of a function associated with a patch at each subdivision of the patch as a subdivision of the function. When the subpatch covers only one picture element, the surface normal is used to compute the intensity of the subpatch at that picture element. The $x_s$, $y_s$ and $z_s$ screen coordinates are used to perform hidden surface removal employing the depth buffer approach. A depth buffer is a frame buffer which provides storage for intensity and depth ($z_s$) information for each picture element of the screen. Initially, the intensity information of the whole frame buffer is set to background intensity and the depth information is set to zero (recall that $z_s$ is the reciprocal depth). When a subpatch covers only one picture element, its $x_s$ and $y_s$ screen coordinates are used to address the buffer. The $z_s$ in the addressed location is read and compared with the $z_s$ of this subpatch. If $z_s$ of this subpatch is larger than the one read, then the intensity and $z_s$ of this subpatch replaces the old values in the addressed location of the buffer; otherwise, nothing is done.

Catmull has devised an efficient algorithm to subdivide bivariate polynomial functions. In particular, subdivision of bicubic functions is quite simple. However, as seen earlier, the screen coordinates of a patch are rational bicubic functions which do not fit into the simple subdivision algorithm. In order to still make use of the simple bicubic subdivision algorithm, Catmull approximates a patch in screen coordinates by taking the control points through the perspective transformation and recreating the bicubic patch in screen coordinate systems with the transformed control points. He claims that the approximation is very close.

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*Subdivision of a patch is the process of subdividing a patch into four smaller subpatches along the midpoints of the two parameters.

As mentioned earlier, the components of the surface normal of a bicubic patch are biquintic. To make use of the simple bicubic subdivision algorithm, Catmull approximates the surface normal of a bicubic patch by a bicubic function.

For texture generation on bicubic patches, Catmull keeps track of the parametric values u and v as each subpatch is subdivided. The u and v parametric values are then used to look up a table of texture modulation values defined on the unit square of the u-v parametric space. This texture modulation value is then added to the intrinsic intensity obtained using the surface normal.

Blinn Algorithm (6). Despite his simple subdivision algorithm, Catmull's algorithm is still quite time-consuming and uses a large amount of memory. To overcome these problems, scan line algorithms have been developed for bicubic patches. Scan line algorithms generate the picture elements on the screen from left to right, top to bottom, as opposed to the random order in Catmull's algorithm. Scan line algorithms allow exploitation of coherence of images. Blinn's algorithm, as well as algorithms discussed in later sections, are scan line algorithms.

In scan line algorithms, one of the important tasks is to find the silhouettes of the patches. After the silhouettes are found, tonal computations (intensity and/or texture modulation) are performed within the silhouettes of the patches. For boundary curve intersections with scan lines, a univariate bicubic function of equation [16] is involved. Blinn uses Newton-Raphson iteration technique to solve for the independent variable with the independent variable found for the previous scan line as the initial guess. Blinn claims that convergence is quite fast.

For silhouette curve intersections with scan lines, a pair of bivariate polynomial functions (one bicubic and the other biquintic) are involved. Blinn uses the bivariate Newton-Raphson iteration technique with the two parameters found for the previous scan line as the initial guess. Since bivariate Newton-Raphson iteration technique is much more involved than the univariate counterpart, generation of silhouette curves are much more difficult than boundary curves. After the independent parametric variables u and v are found for scan line intersections of the boundary curves and the silhouette curves, they are substituted into equation [12] to obtain the $x_s$ coordinates of the intersections.

For intensity computation as well as texture generation, the (u,v) parametric values have to be obtained for each picture element along each scan line covered by a patch. The (u,v) parametric values for each picture element on each scan line have to be obtained by solving the pair of bivariate cubic functions of equations [19] and [20]. The (u,v) values are then substituted into equations of the components of the surface normal to obtain the surface normal for intensity computation.

To avoid having to compute the (u,v) values for each picture element covered by a patch, Blinn introduced a generalized silhouette concept to generate (u,v) for the scan line intersections of 16 generalized silhouette curves on a particular scan line (say k) by solving the following equations for 16 different θ:

$$y_s = UNV^T/ULV^T = k$$

$$a(u,v)\sin\theta + d(u,v)\cos\theta = 0$$

Note that θ=0° and 180° correspond to the silhouette curves discussed earlier. The intensity is then calculated exactly at the scan line intersections of these 16 generalized curves. In between these 16 intersections the intensity is linearly interpolated.

For texture generation on a patch, the exact (u,v) parametric values of each picture element on the patch are used to look up a texture modulation table as in Catmull's algorithm.

Whitted Algorithm (7). Whitted's algorithm is similar in nature to Blinn's but avoids the difficult computation involved with the solution of a pair of bivariate polynomial functions necessary in Blinn's algorithm. His approach is to split a patch into smaller subpatches. If the silhouette curve passes through a subpatch then the segment of the silhouette curve within this subpatch is approximated by a univariate cubic curve similar in form to a boundary curve. Therefore, the silhouette curve of a patch is approximated by piecewise cubic curves. Since the boundary curves as well as the approximated silhouette curves are now univariate cubic curves, Whitted's algorithm only has to deal with univariate cubic curves. As in Blinn's algorithm, Whitted also uses the Newton-Raphson iteration technique for the solution of univariate cubic equations. Both algorithms share a basic problem: Although their numerical iteration technique converges quite rapidly, it frequently suffers from stability problems associated with singularity points.

Lane-Carpenter Algorithm (8). The Lane-Carpenter algorithm avoids problems associated with numerical iteration techniques. Their approach is to employ a subdivision algorithm similar to Catmull's. However, unlike Catmull's algorithm, subdivision is terminated once a subpatch is deemed to be within a preset tolerance of being planar, at which time the four corner points of the subpatch are used to define a quadrilateral approximating the subpatch. This quadrilateral is then scan-converted with conventional polygonal scan conversion algorithms.

Clark Algorithm (9). Clark's algorithm is similar in nature to the Lane-Carpenter algorithm. They differ mainly in the mathematics involved in the subdivision and the test for planarity. Clark uses the central differencing subdivision technique which is faster than the Bezier (or Bernstein) subdivision technique used by Lane and Carpenter. In planarity test, Clark's algorithm is again faster.

The advantage of the Clark and Lane-Carpenter subdivision algorithms is that it is not necessary to consider the silhouette curves explicitly. In addition, the planarity test is based on the screen-space curvature of the subpatches; consequently, an object modeled with bicubic patches is essentially being approximated dynamically with a number of quadrilaterals depending on the screen sizes of the patches. The number of quadrilaterals is larger when the object is close than when it is far away. The minimum number of quadrilaterals is equal to the number of bicubic patches used in defining the object. This has the effect of continuously changing the level-of-detail polygonal representation of the object.

On the other hand, since the objects eventually displayed on the screen are approximated by polygons, the usual undesirable effects of modeling objects by polygons will be seen on images produced by the Clark and Lane-Carpenter algorithms. Of course, if the tolerance in the planarity test is set to be very small, then a smooth image will result. However, in this case the number of polygons to be scan-converted will be very large.

## Inaba Patches

Inaba patches (3) are special cases of bicubic patches. Only one component of the surface definition of an Inaba patch is bicubic; the other two components are linear in one of the two independent variables as indicated below:

$$x_e = u$$

$$y_e = v$$

$$z_e = UBZ_eB^TV^T$$

Inaba patches are appropriate for modeling terrain. Their major advantage over the more general bicubic patch is that, while the surface normal in the pilot's eye coordinate system of a bicubic patch is biquintic, that of an Inaba patch is bicubic. Thus, intensity computation using the surface normal is easier in Inaba patches than in general bicubic patches.

## Biquadratic Patches

A biquadratic patch is a parametric patch whose three components of parametric surface definition are biquadratic in two independent variables as follows:

$$x_e = [u^2\ u\ 1]\ BX_eB^T\ [v^2\ v\ 1]$$

$$y_e = [u^2\ u\ 1]\ BY_eB^T\ [v^2\ v\ 1]$$

$$z_e = [u^2\ u\ 1]\ BZ_eB^T\ [v^2\ v\ 1]$$

$X_e$, $Y_e$ and $Z_e$ are 3x3 matrices defining nine control points. B is a constant 3x3 matrix. Because of the lower degree of the polynomials involved, biquadratic patches are less flexible for modeling free-form curvilinear objects, and smoothness across patches is more difficult to maintain than the bicubic counterpart. On the other hand, the computations involved for their rendition are less complicated.

It is conceivable that one could apply Whitted's approximation technique in bicubic patches to biquadratic patches in the following manner. A biquadratic patch is split into smaller subpatches. If the silhouette curve passes through the subpatches, it is approximated by a piecewise univariate quadratic curve. Since now it is only necessary to deal with univariate quadratic curves, the task of finding the silhouette intersections with scan lines is simplified. The independent variable of univariate quadratic curve intersections with scan lines can be solved either iteratively using Newton-Raphson technique or analytically by the solution of a quadratic equation.

## QUADRIC SURFACES

Quadric surfaces are surfaces defined by a second degree equation as follows:

$$a_1x_e^2 + a_2y_e^2 + a_3z_e^2 + a_4x_ey_e + a_5x_ez_e +$$

$$a_6y_ez_e + a_7x_e + a_8y_e + a_9z_e + a_{10} = 0$$

There are a total of 17 types of quadric surfaces described by this general second degree equation (10). Among these 17 types of quadric surfaces, five are imaginary and two are planar, and so only 10 of them are real curvilinear surfaces and are useful for modeling man-made curvilinear objects such as water towers, oil storage tanks, silos and other aircrafts.

Since all 10 types (except real ellipsoid) of real quadric curvilinear surfaces have infinite extent, we are only concerned with those bounded by planes to form cylinders, cones and frustums, etc. Planar ellipses are useful for modeling bomb craters and other man-made features. Moreover, the bounding of real quadric surfaces by planes results in planar ellipses. Therefore, we consider quadric surface generation as the generation of bounded real curvilinear quadric surfaces and planar ellipses. These quadric surfaces can be combined together to model more complicated man-made curvilinear objects.

It can be shown that the silhouettes of these quadric surfaces are composed of either straight lines or conic sections. There exist efficient algorithms for finding silhouettes of these quadric surfaces as well as their intersections with scan lines (11).

An efficient scheme for intensity computation for quadric surface also exists (11). This intensity computation involves the incremental generation of two quantities and their subsequent division.

## PLANAR SURFACES

Because of the ease of real-time rendition of planar surfaces, most real-time CGI systems approximate curvilinear objects by planar surfaces. The silhouettes of planar surfaces are easy to generate because they are composed of straight lines.

In earlier real-time CGI systems, intensity for each planar surface was constant and was computed by calculating the dot product of the sun's illumination direction vector with the surface normal vector of the planar surface. As a result, curvilinear objects looked faceted. To eliminate the faceted appearance, Gouraud (12) introduced an algorithm for continuous intensity shading across boundaries of planar surfaces. His algorithm involves linear interpolation of intensity from intensities at the vertices of planar polygons and is quite easy to implement in real time. This algorithm improves dramatically the appearance of curvilinear objects but does not eliminate completely the faceted appearance because even though the intensity is continuous, the intensity gradient is not. Another shortcoming is that the silhouette of the curvilinear object is still composed of straight edges.

Phong (13) introduced an improvement of intensity computation for curvilinear objects approximated by planar surfaces by linearly interpolating the surface normals instead of intensities within planar polygons from those at the vertices of the polygons. The linearly interpolated surface normal is then unitized before being used for intensity computation. Phong also introduced an extra term in the intensity illumination model to include specular reflection which adds highlights on shiny objects. Because of the complex computations required, no real-time CGI systems have incorporated the Phong algorithm. Recently, a faster implementation of the Phong algorithm has been independently found by Yan (11) and Duff (14).

## COMPARISON OF VARIOUS CURVILINEAR OBJECT GENERATION TECHNIQUES

Having introduced the various known techniques for computer generation of curvilinear objects, we will now compare them in terms of several attributes in the following subsections.

### Ease of Generation of Silhouettes of Objects

The generation of silhouettes of curvilinear objects involves first the finding of the definitions of the silhouettes and, second, the finding of their intersections on scan lines given their definitions. The following lists the various curvilinear object generation techniques in the order of decreasing ease of generation of silhouettes.

Planar Surface Technique. The silhouettes of objects approximated by planar surfaces are composed of straight lines (first degree curves). The definitions of these straight lines, as well as their intersections on scan lines, are the easiest to obtain.

Quadric Surface Technique. The silhouettes of objects modeled with this technique are composed of conic sections (second degree curves). Efficient algorithms exist to find the definitions as well as the scan line intersections of these conic sections.

Biquadratic Patch Technique with Whitted's Approximation. The silhouettes of objects produced with this technique are composed of univariate quadratic (second degree) curves. Algorithms exist to find their intersection on scan lines. However, finding the definitions of these univariate quadratic curves is difficult and involves the splitting of patches into smaller subpatches and the approximation of silhouette curves by piecewise univariate quadratic curves.

Lane-Carpenter and Clark Bicubic Patch Techniques. The silhouettes of objects eventually used for display are straight lines and, therefore, their intersections on scan lines are easy to find. However, the finding of these straight-line silhouettes involves expensive subdivision of bicubic patches and tests for planarity.

Whitted Bicubic Patch Technique. The silhouettes of objects produced with this technique are composed of univariate cubic (third degree) curves. Univariate Newton-Raphson iteration technique is necessary to solve for the scan line intersections of these silhouettes. The definitions of these univariate cubic curves are found by splitting bicubic patches into smaller subpatches and approximation of silhouette curves by piecewise univariate cubic curves.

Blinn Bicubic Patch and Inaba Patch Techniques. The silhouettes of objects produced with these techniques are composed of boundary curves which are univariate cubic curves and silhouette curves which are defined by a pair of bivariate polynomial functions. Bivariate (univariate) Newton-Raphson iteration technique is employed to find intersections of silhouette (boundary) curves with scan lines.

Catmull Bicubic Patch Technique. Catmull's technique differs from the rest of the techniques in that silhouettes of objects are implicitly obtained when a patch is recursively subdivided until all subpatches cover only one picture element. This process is expensive.

### Ease of Intensity Computation Within Silhouettes of Objects

Intensity computation on surfaces of objects within the silhouettes involves finding the unitized surface normals of the surfaces and then performing a dot product of the sun's direction vector with these unitized surface normals. Curvilinear object generation techniques usually employ approximations to the above computation to speed up the intensity computation process. The following lists the various techniques in the order of decreasing ease of intensity computation.

Planar Surface Technique. Curvilinear objects approximated by planar polygons have a unitized surface normal associated with each vertex of the polygonal approximations. The unitized surface normal at each vertex approximates closely the surface normal of the real curvilinear objects. The intensity at each vertex is then computed and intensities within the polygons are linearly interpolated from those at the vertices. Thus, intensity computation for objects modeled with this technique is quite simple.

Quadric Surface Technique. For quadric surfaces the surface normals are linear in the screen $x_s$, $y_s$ and $z_s$ coordinates. This allows a close approximation of surface normal within the silhouette of a quadric surface by a piecewise linear approximation. An efficient algorithm exists to perform the intensity computation using the piecewise linearly interpolated surface normal. This intensity computation involves the incremental generation of two quantities and their subsequent division.

Parametric Surface Techniques. The surface normal as well as the surface description of parametric surfaces are defined on the same two independent variables (u,v). To compute intensity exactly at each picture element occupied by a visible parametric surface patch, it is necessary to find the (u,v) parametric values for each of these picture elements. The (u,v) pair is then substituted into the equations of the surface normal to obtain the surface normal for intensity computation. This is quite costly in processing time. To speed up intensity computation on parametric surfaces, the surface normals and intensities are computed exactly only at certain strategic points within parametric surface patches. Intensities at points other than these strategic points are linearly interpolated. In the Clark and Lane-Carpenter approach, the strategic points are the corner points of subpatches which are deemed close to being planar. In the Blinn approach, there are 16 strategic points along each scan line covered by a patch. In the Whitted approach, the boundary curves of subpatches and the approximated silhouette curves are strategic points. In the Catmull approach, every point is a strategic point.

For parametric surface techniques such as those of Catmull, Clark, and Lane-Carpenter which employ subdivision of patches, the components of surface normal are subdivided along with the surface patches. Therefore, no substitution of (u,v) values into surface normal equations is necessary. However, the subdivision of surface normal is quite expensive.

Ease of Texture Generation Within Silhouettes of Objects.

Texture generation on an object is the process of mapping a two-dimensional texture modulation pattern onto the surface of the object. In order to have the texture pattern spatially fixed to the surface, each point on the surface must be associated with a fixed point in a two-dimensional space called texture mapping space. For each visible point on the surface, the coordinates of its associated point in the texture mapping space are used to look up a two-dimensional texture modulation intensity look-up table. The texture modulation intensity looked up is then added to the intrinsic intensity of the surface.

A major step in texture generation on a surface is as follows. For each visible picture element of the surface, find the coordinates of its associated point on the texture mapping space given its $x_s$ and $y_s$ screen coordinates and the geometry of the surface. We will refer to the above step as inverse transformation. Texture generation is very sensitive to error in the inverse transformation process; a slight error in performing inverse transformation will result in texture pattern which is not spatially fixed to the surface when a dynamic sequence of texture generation is viewed. Therefore, inverse transformation has to be accurately performed for each visible point of a surface which is to receive texture; no coarse approximation to the inverse transformation can be expected to work. The following lists the various curvilinear object generation techniques in the order of decreasing ease of performing inverse transformation to the appropriate texture mapping space.

Planar Surface Technique. Since each point on a planar surface is associated with a fixed point on the $x_e$-$y_e$ two-dimensional space, the $x_e$-$y_e$ space is an appropriate texture mapping space for planar surfaces. One major computation involved in the inverse transformation to this texture mapping space is the finding of $z_s$ of a point on the planar surface given its $x_s$ and $y_s$ screen coordinates. It can be shown that for planar surfaces $z_s$ is linear with $x_s$ and $y_s$. Therefore, $z_s$ for planar surfaces can be incrementally generated.

Quadric Surface Technique. As in planar surfaces, $x_e$-$y_e$ space is an appropriate texture mapping space. Again, the finding of $z_s$ of a point on the quadric surface, given its $x_s$ and $y_s$ screen coordinates is a major computation of the inverse transformation. However, unlike planar surfaces, $z_s$ for quadric surfaces is not linearly related to $x_s$ and $y_s$ and its evaluation is consequently more difficult.

Parametric Surface Techniques. Since each point on a parametric surface is associated with a fixed point on the u-v parametric space, the u-v parametric space is an appropriate texture mapping space for parametric surfaces. To perform the inverse transformation for each and every visible picture element of parametric surfaces, the solution of a pair of bivariate polynomial functions is required. Thus, texture generation on parametric surfaces is quite difficult.

Image Quality

We consider two aspects of image quality here. The first is the smoothness and naturalness of silhouettes of objects. The second is the realism of illumination effect rendition within the silhouettes. The following lists various curvilinear object generation techniques in the order of decreasing image quality.

All Parametric Surfaces Techniques Except Clark and Lane-Carpenter Techniques. Curvilinear objects generated with these techniques have smooth silhouettes. Moreover, since information is available for exact calculation of surface normal at every point of the surfaces, images with extremely realistic illumination effect using sophisticated illumination models can be generated.

Quadric Surface Technique. Man-made curvilinear objects generated with this technique also have smooth silhouettes. Moreover, as in parametric surface techniques, information is available for the exact calculation of surface normal for rendition of realistic illumination effect.

Clark and Lane-Carpenter Techniques. Since curvilinear objects generated with these techniques are eventually approximated by planar polygons, the silhouettes of curvilinear objects are still approximated by straight lines. However, since information is available for exact calculation of surface normals within the silhouettes, realistic illumination effect can be generated within the silhouettes.

Planar Surface Technique. The silhouette of curvilinear objects produced with this technique are composed of straight lines. Moreover, surface normals are available only at the vertices of the polygonal approximation. Thus, a surface normal within polygonal surfaces can only be approximated by interpolation, resulting in less realistic rendition of illumination effect than the other techniques.

Data Base Compactness

For free-form curvilinear object modeling, the parametric surface approach will result in a more compact data base than the planar surface approach. The quadric surface approach is not appropriate for modeling free-form curvilinear objects.

For man-made curvilinear objects such as water towers, silos, oil storage tanks, the quadric surface approach will result in the most compact data base. The parametric surface approach will result in a less compact data base and the planar surface approach will result in the least compact data base.

Flexibility of Modeling Free-Form Curvilinear Objects

The parametric surface approach is by far the most flexible and natural for modeling free-form curvilinear objects. Images generated with this approach have proven to be smooth and natural. Among the different techniques within the parametric approach, those using higher order polynomials will be more flexible in modeling free-form curvilinear objects than lower order ones. Therefore, bicubic patches are the most flexible, Inaba patches are less flexible, and biquadratic patches are the least flexible for modeling free-form curvilinear objects.

The planar surface approach is quite flexible for modeling free-form curvilinear objects. Unfortunately, images generated with this approach have undesirable unnatural artifacts discussed above.

The quadric surface approach is the least flexible for modeling free-form curvilinear objects.

## CONCLUSION

Three approaches to computer generation of curvilinear objects have been surveyed. These three approaches are compared in terms of six attributes. The planar surface approach is first in three out of the six attributes, namely, ease of generation of silhouettes, ease of intensity computation and ease of texture generation. Texture generation provides effective motion and attitude cues for pilot training. We feel that planar surface approach will continue to prevail in real-time CGI systems for flight training.

The quadric surface approach is second in ease of silhouette generation, ease of intensity computation, ease of texture generation and image quality. It is first in data base compactness for modeling man-made curvilinear objects. We feel that quadric surface generation with smooth shading (intensity computation) but without texture generation is a viable addition to real-time CGI systems to augment planar surface generation with smooth shading and texture generation.

For curvilinear objects, the parametric surface approach is first in image quality, data base compactness, and flexibility of modeling free-form curvilinear objects. Unfortunately, it is substantially more difficult than the other two approaches in silhouette generation, intensity computation, and texture generation. Parametric surface approach will prevail in applications where image quality is important and real-time generation is not important. Such an application is animation for television commercials.

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# JOINING TECHNIQUES FOR OPTICALLY COMBINED VISUAL DISPLAY SYSTEMS

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Since the introduction and FAA certification of VITAL in March, 1972, computer generated image display modules containing a spherical mirror, beamsplitter, and cathode ray tube (CRT) have become very familiar to flight simulator visual system users. Increased utilization of simulators has created the need for expanded visual system fields of view. CGI techniques and creative variations to these basic display modules are satisfying this need.

In less than one decade, visual display systems have progressed from single module, single channel to multiple channels using optically combined modules. To provide for these broader requirements, McDonnell Douglas Electronics Company (MDEC) has developed three separate approaches employing optical combining techniques: Modular, Wide Field of View and Zero Gap. All are capable of being optically joined into multiple module configurations with overlapping imagery, and each exhibits a different set of tradeoff considerations. This paper discusses field of view (FOV), and describes the joining characteristics for each technique. It concludes by presenting photographs of imagery from our latest configurations, the Wide Field of View and Zero Gap overlapped displays.

## FIELD OF VIEW

The multichannel systems which began to emerge in 1973 necessitated the coordination of the several modules around the cockpit. Determination of module location requires a careful analysis of training tasks and almost always involves judgemental compromises. Considerations must include modular structural constraints, cockpit geometry and head motion. Suppliers of visual systems must also recognize there are significant mission and head motion differences between military fighters and commercial aircraft. Regardless of aircraft type, however, an understanding of FOV characteristics is necessary to determine which of the three optical module joining techniques is best suited for a particular visual system.

Total FOV and instantaneous FOV are two terms used in discussing visual display systems. Although widely used, there are no generally accepted definitions for these terms. At MDEC, we use the following first order definitions for horizontal or vertical maxima:

Total Field of View, (TFOV) =

$$2(\mathrm{Sin.})^{-1}\left[\frac{\text{maximum CRT dimension}}{2(\text{Optical system focal length})}\right]$$

Instantaneous Field of View, (IFOV) =

$$2(\mathrm{Sin.})^{-1}\left[\frac{\text{maximum mirror dimension}}{2(\text{Eye to mirror distance})}\right]$$

Equating these terms to the real world situation, TFOV is comparable to the outside world scene and IFOV is comparable to a window frame through which the outside world is viewed. TFOV and IFOV may be obstructed by module side panels or beamsplitter supports, by intrusion of the CRT, or by aircraft structure.

The location of the IFOV changes in the azimuth-elevation coordinate system with head motion. Depending upon the exact hardware configuration and amount of observer head movement, the IFOV may not be large enough to continue the visibility of some portion of the TFOV. To help visualize these complex FOV relationships, MDEC developed a computer program, with various plotting options, to correctly illustrate the relationship of mirror, CRT, beamsplitter and TFOV in an azimuth-elevation coordinate system. The two plots shown in Figure 1 demonstrate the effects of observer head motions, in this example 7.5 inches left and 3 inches down from nominal, on a single module located "straight ahead" of the pilot. The plotting option used in the lower half of the Figure clearly shows that only a portion of the CRT is visible from the extreme viewing position.

Each of the three joining techniques for combining optical modules establishes specific relationships between T and IFOV's.

## JOINING TECHNIQUES

The new systems now being used demanded new solutions to old problems. Several forms of electrical distortion, for example, become critical and can limit system performance. However, these problems have been solved separately and are readily separable from the purely optical considerations involved in expanding system FOV's. In this paper we will concentrate on the optical characteristics at the module edges of these three distinct methods of joining displays with overlapping imagery.

## THE MODULAR OPTICS TECHNIQUE

The term "Modular Optics" refers to a family of optical assemblies each containing a spherical mirror and beamsplitter. Modules have a $36^{o} \times 48^{o}$ TFOV. The difference between the modules is mainly in the size of horizontal IFOV as shown in Figure 2. All modules have side panels (opaque edges). Where modules provide overlapped imagery, adjacent sides represent a common cut through the center of a sphere. TFOV horizontal half-angles exceed corresponding IFOV half-angles by $1^{o}$, resulting in a TFOV overlap of $2^{o}$. These characteristics allow modules to be positioned side-by-side with freedom to have relative vertical offsets, a major distinction and a frequently significant operational advantage over the Zero Gap technique to be described later. Monocularily, beamsplitter joints between modules subtend about $1.5^{o}$. With binocular viewing, no full length beamsplitter joining gaps are seen from the reference position.

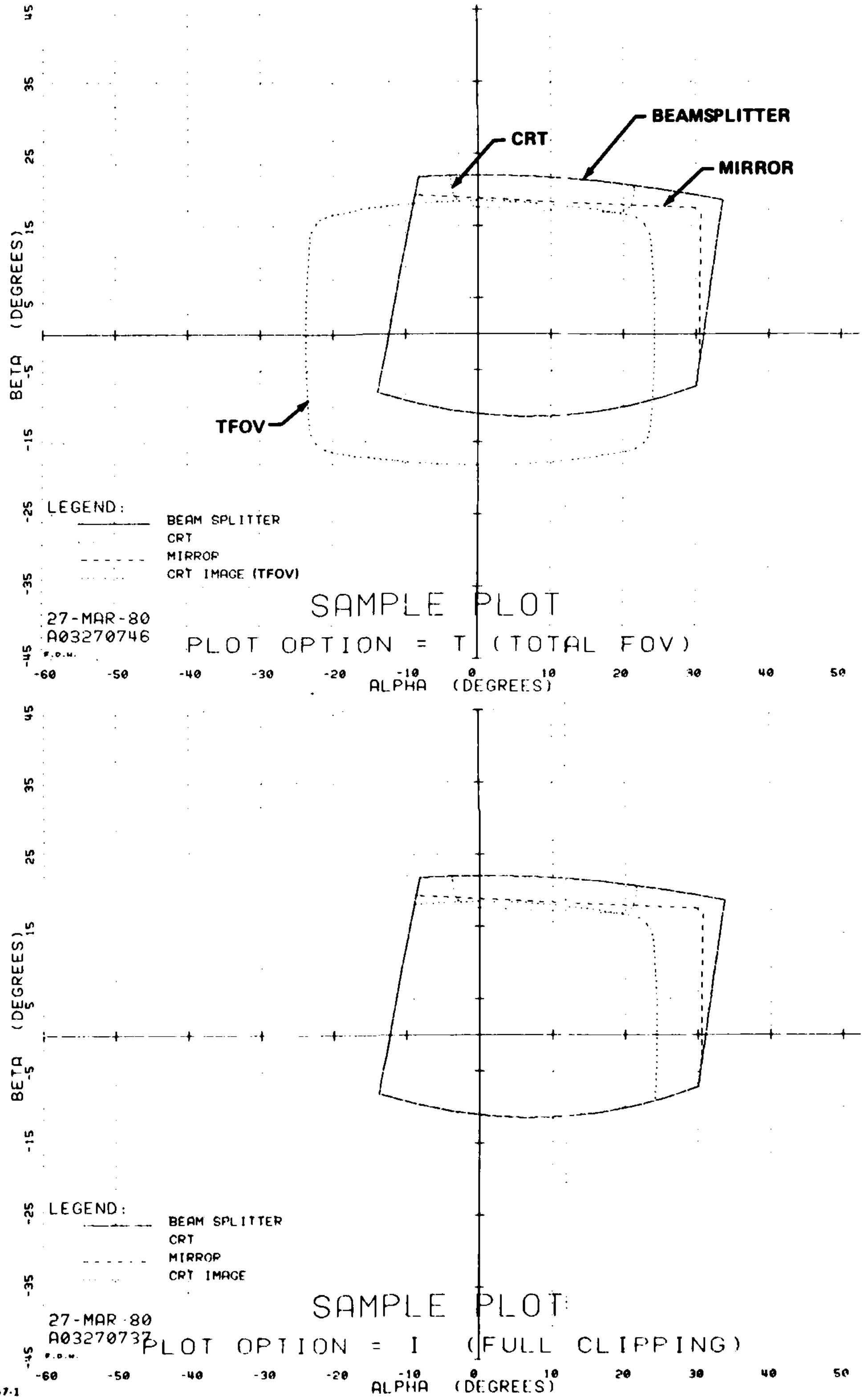


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FIGURE 1. SAMPLE PLOTS SHOWING EFFECTS OF HEAD MOVEMENT

Note that, with one exception, FOV sketches, as well as the photographs of the displays which follow later, generally represent monocular viewing: There are just too many lines on plots representing binocular viewing for easy comprehension.

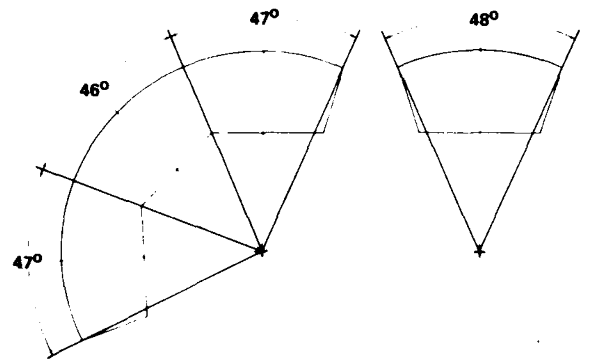


FIGURE 2. MODULAR OPTICS PACKAGE VARIATIONS

The effects of head movement on joined Modular Optics are shown in Figure 3, which illustrates two viewing positions of a generalized three module display system. Binocular viewing from the nominal head position is represented at the junction between right-hand and center modules. Viewing is essentially gap-free. Binocular viewing from left of the nominal head position is represented at the junction between left-hand and center modules. Oblique viewing of the side panels is occluding a portion of the center window imagery. All of the left module's imagery near the overlap region is seen. With Modular Optics, head movement from the nominal head position is evidenced by the black band developing between display modules. Black band growth occurs at a rate of about 1 3/4° per inch of head movement.

An interesting additional variation to this display package concept is illustrated in Figure 4. This Vertical Package module is now being applied to several situations in which the quarter display has a vertical, rather than horizontal, orientation to permit increased up-viewing (as in banked turns) and down-viewing (runway edges during landing phase) with one display package. This optical package was developed to eliminate severe beamsplitter reflection problems from cockpit lighting which may occur with a simple 90° rotation of a conventional optical module. One tradeoff in use of this optical package is a slightly larger, 3° gap between adjacent displays.

Modular Optics have proven quite useful in meeting a wide range of training requirements. This is particularly true in situations for which relative vertical offset between adjacent modules is important. These packages have been implemented with a variety of geometric parameters to satisfy different operational requirements: For example, we have incorporated spherical mirrors with radii of 49 1/2, 58 and 80 inches in various systems.

THE WIDE FIELD OF VIEW TECHNIQUE

The Wide Field of View (WFOV) optical system represents a significant departure from the classic 36° x 48° module because it provides a TFOV of 60° x 45° in a single module. Similar electronic assemblies including the same CRT are used for WFOV and Modular Optics. The larger TFOV is obtained by using a different mirror radius and a multielement relay lens to shorten the optical system focal length.

This is a pupil-forming system with a 9 inch diameter pupil. As shown schematically in Figure 5, the system can be packaged with the 60° axis vertical, and this large vertical subtension makes relative vertical offsets between adjacent modules less important. With zero relative elevation difference between modules, the adjacent module beamsplitters intersect in a line subtending the same azimuth angle as the edges of the module mirrors, and side panels can be removed. An 8° TFOV overlap between modules provides full-pupil viewing. Vignetting within the relay lens occurs only at the extreme corners of the display field. Beamsplitters for the 60° vertical orientation are long (5 feet) and require substantial (1 inch wide) supports. Except for a small diamond shaped area, the beamsplitter supports do not block the binocular image.

The primary advantages of the WFOV are its 60° x 45° TFOV and its ability to provide essentially gap-free overlapping TFOV's for binocular viewing with head motion. One anticipated disadvantage of the WFOV optical system was its 9 inch diameter pupil. However, experience has now shown that in a single seat fighter cockpit viewing application this pupil size is completely acceptable. The first three module installations using WFOV are installed and operational. The principal application for these systems is for air-to-air intercept and weapons delivery training. A three-module FOV diagram and the visual system are shown in Figure 6.

THE ZERO GAP TECHNIQUE

The advantage of relative vertical offset capability offered by Modular Optics is sometimes overshowed by the desire to remove any gap at all between adjacent displays. For this purpose a Zero Gap optical joining technique was developed.

Zero Gap optical modules differ from Modular Optics primarily in the amount of TFOV overlap and in removal of the side panels between adjacent displays. CRT shape and practical choices of mirror radius limit the overlap to a maximum of about 8°. There can be no relative vertical offset between adjacent displays or the beamsplitter planes would not have the line intersection necessary to allow elimination of the side panels. Beamsplitter dimensions are small enough that gap-producing beamsplitter supports are not required. A large single mirror is used for two-module Zero Gap displays to preclude mirror alignment errors and mirror radius mismatch, both possible with use of two mirrors.

The principal Zero Gap viewing benefit is gapless viewing with head motion, up to the limits of overlap. Implemented with the full 8° overlap, allowable head movement before a gap develops is 5

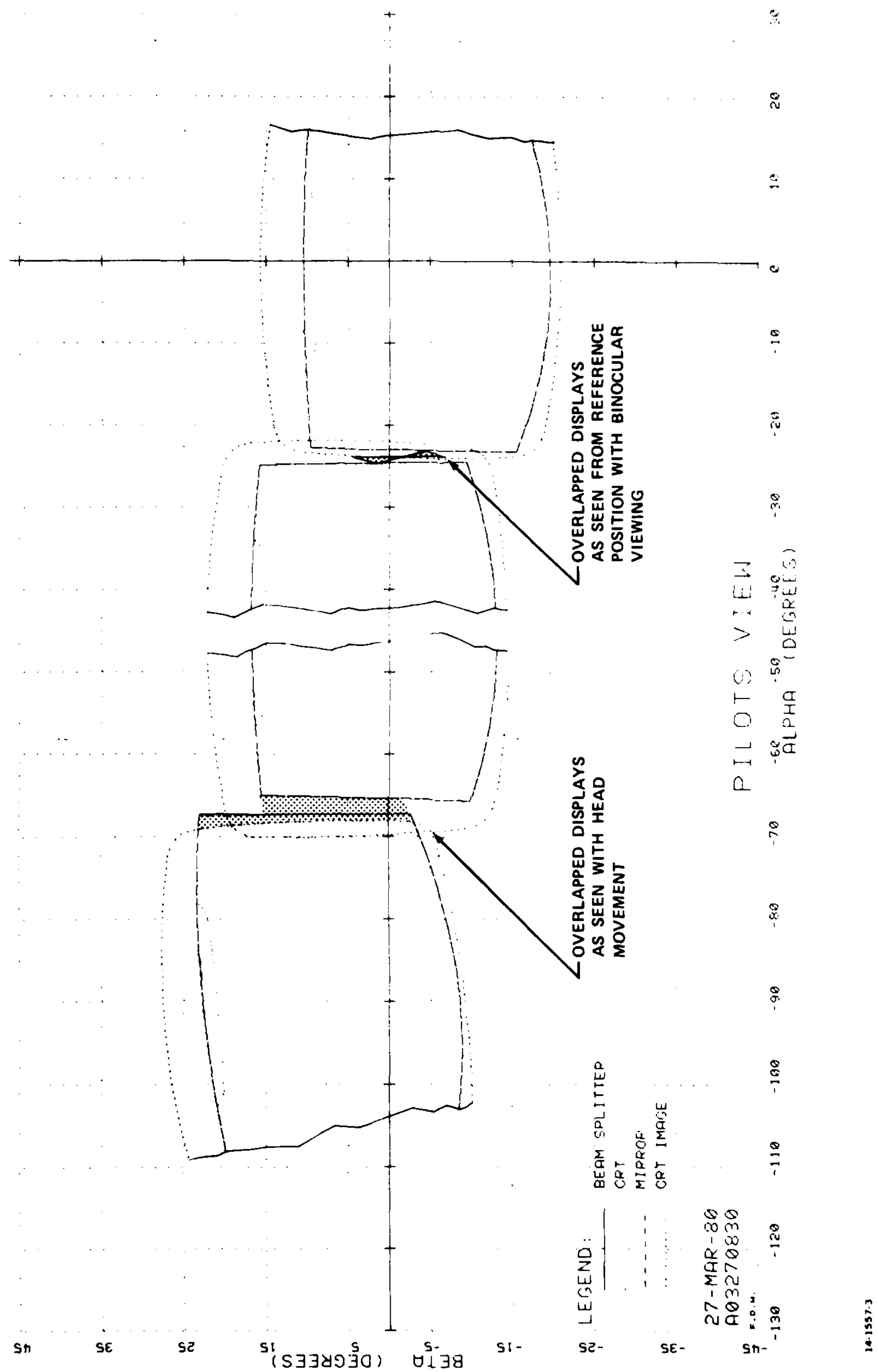


FIGURE 3. TWO BINOCULAR VIEWS OF JOINED MODULAR OPTICS

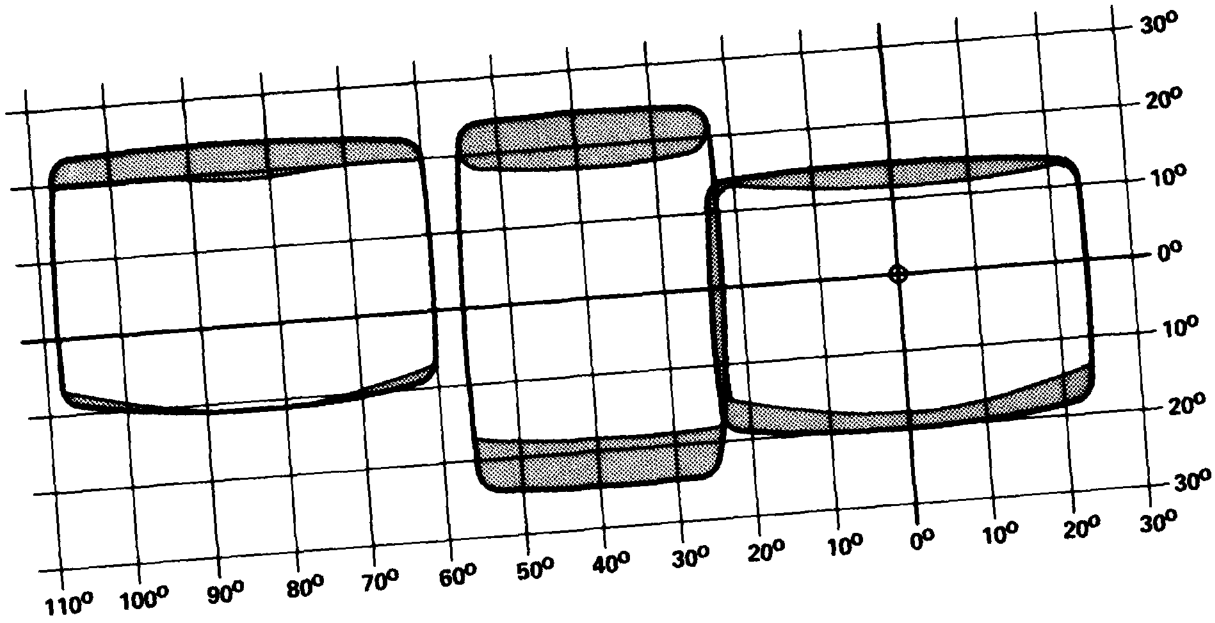


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FIGURE 4. VERTICAL PACKAGE MODULE

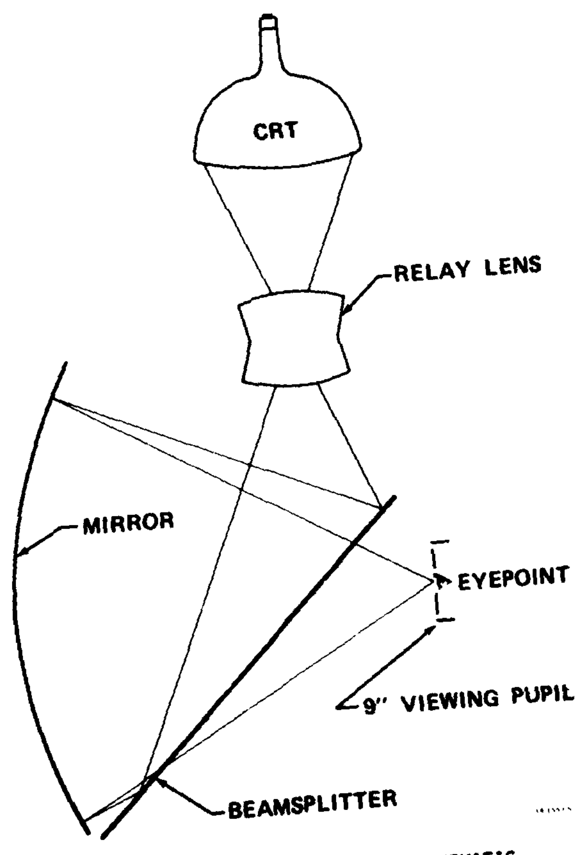
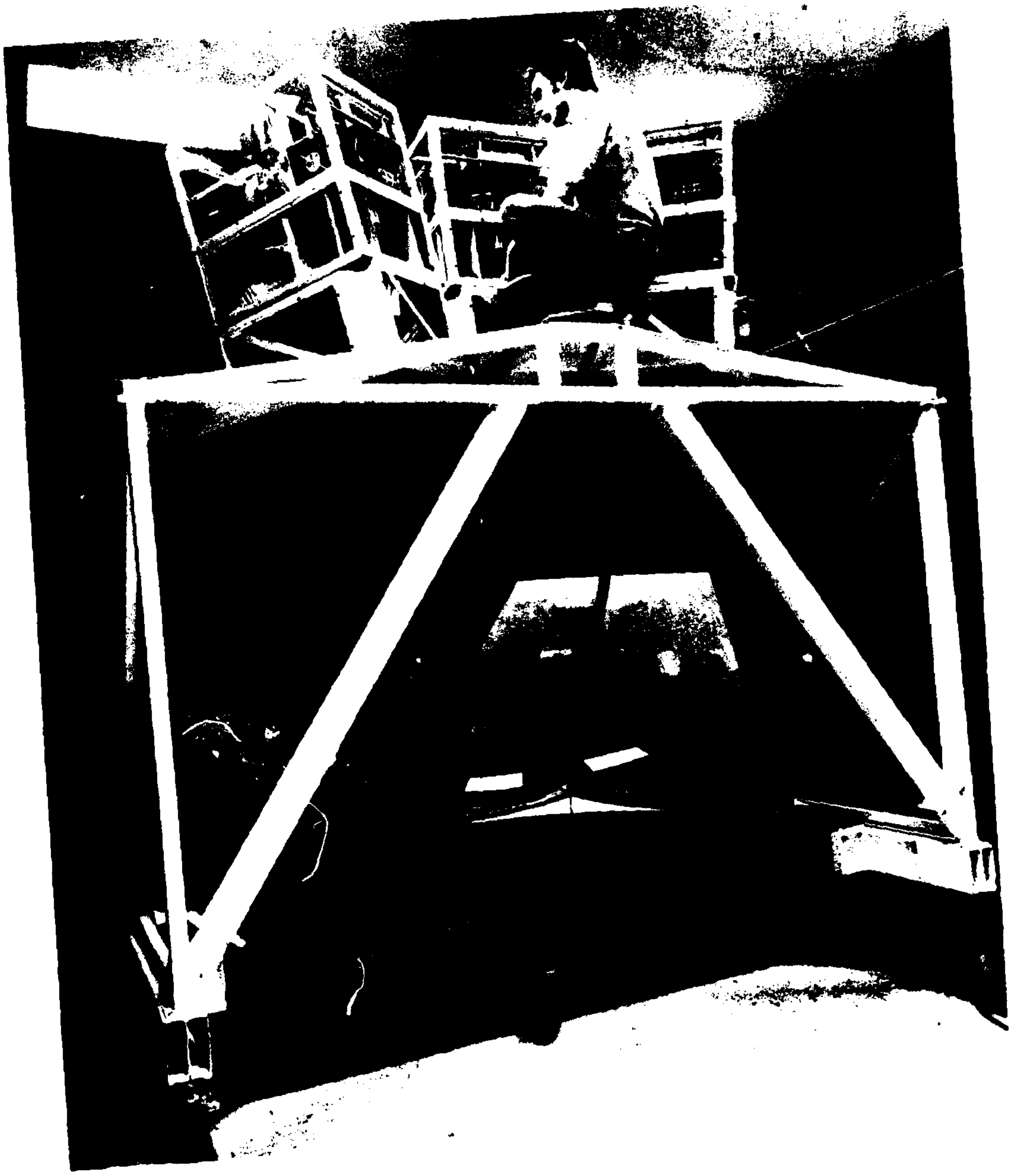
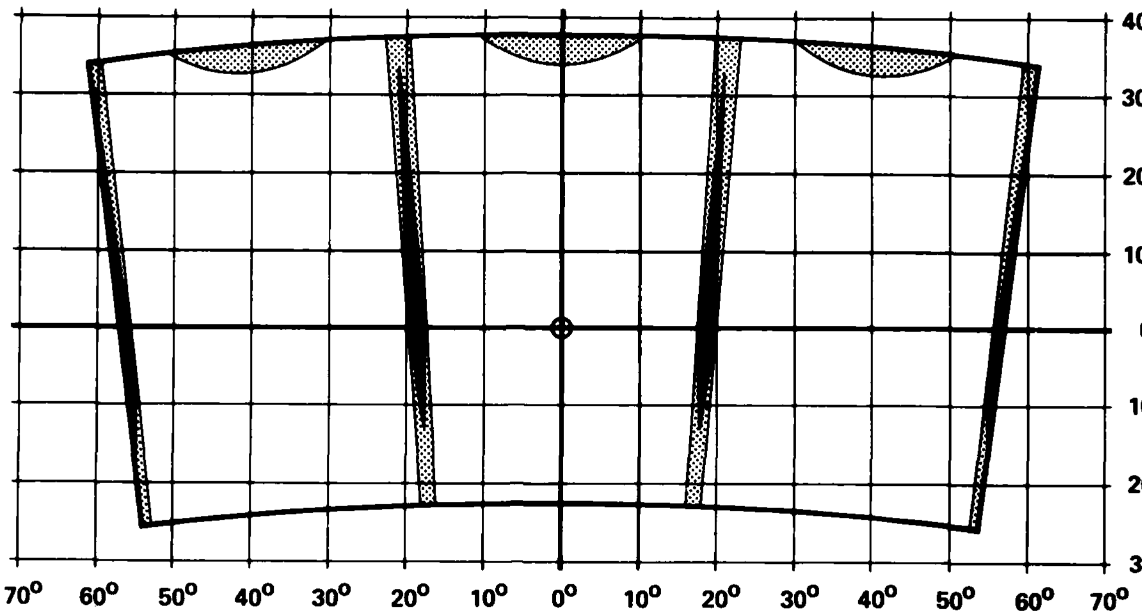



FIGURE 5. WFOV OPTICAL SCHEMATIC





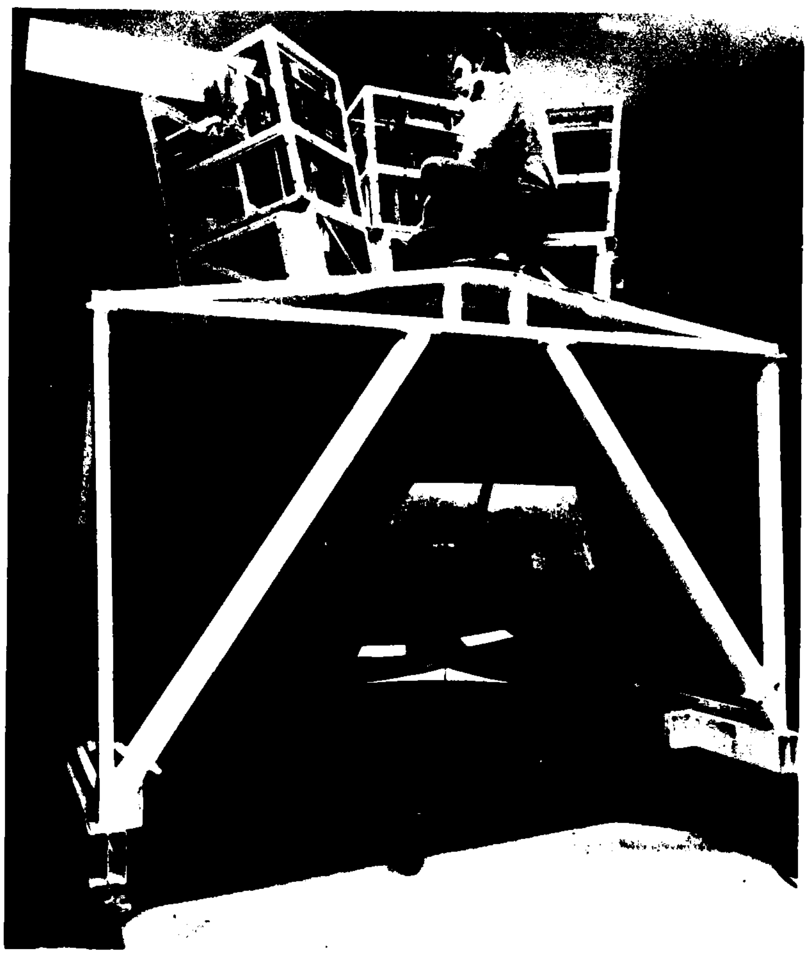



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FIGURE 6. THE JA37 VISUAL SYSTEM

inches for binocular viewing and 3 3/4 inches for monocular viewing. Figure 7 illustrates the condition which exists for head movement of 5 1/4 inches, the position where a gap begins. The triangular gap will enlarge with additional head motion to the left, at a rate of about 1 3/4° per inch of movement. The primary limitation of the Zero Gap joining technique is inability to provide relative elevation offsets across the joined displays.

## SYSTEM PERFORMANCE

Many combinations of display modules are possible. Figure 8 summarizes some recent VITAL IV installations using up to seven display modules per cockpit. Multiwindow display systems with narrow or zero gaps between adjacent modules must have good alignment error correction for acceptable system performance. Display CRT and related electronic deflection errors which must be reduced are shown in Figure 9.

Alignment procedures have been specifically developed for these new overlapped display systems. These procedures, conducted by the simulator technician using only electrical adjustments, have proven effective in achieving the required reduction of electrical/optical errors.

Development of The Zero Gap optical joining technique was begun at MDEC in 1975. Only recently, however, have we obtained the improved electrical components and mirrors of adequate quality required for this type display. Consistent, high quality mirror production is now being achieved in our new mirror fabrication facility.

## CONCLUSION

As a result of some innovative but straightforward optical design work, impressively large field of view coverage is now appearing in visual systems. Large field of view, alone, no longer dictates high-cost visual equipment. With these display solutions now available, military and commercial training Program Managers have more flexibility to satisfy broader demands in training through simulation.

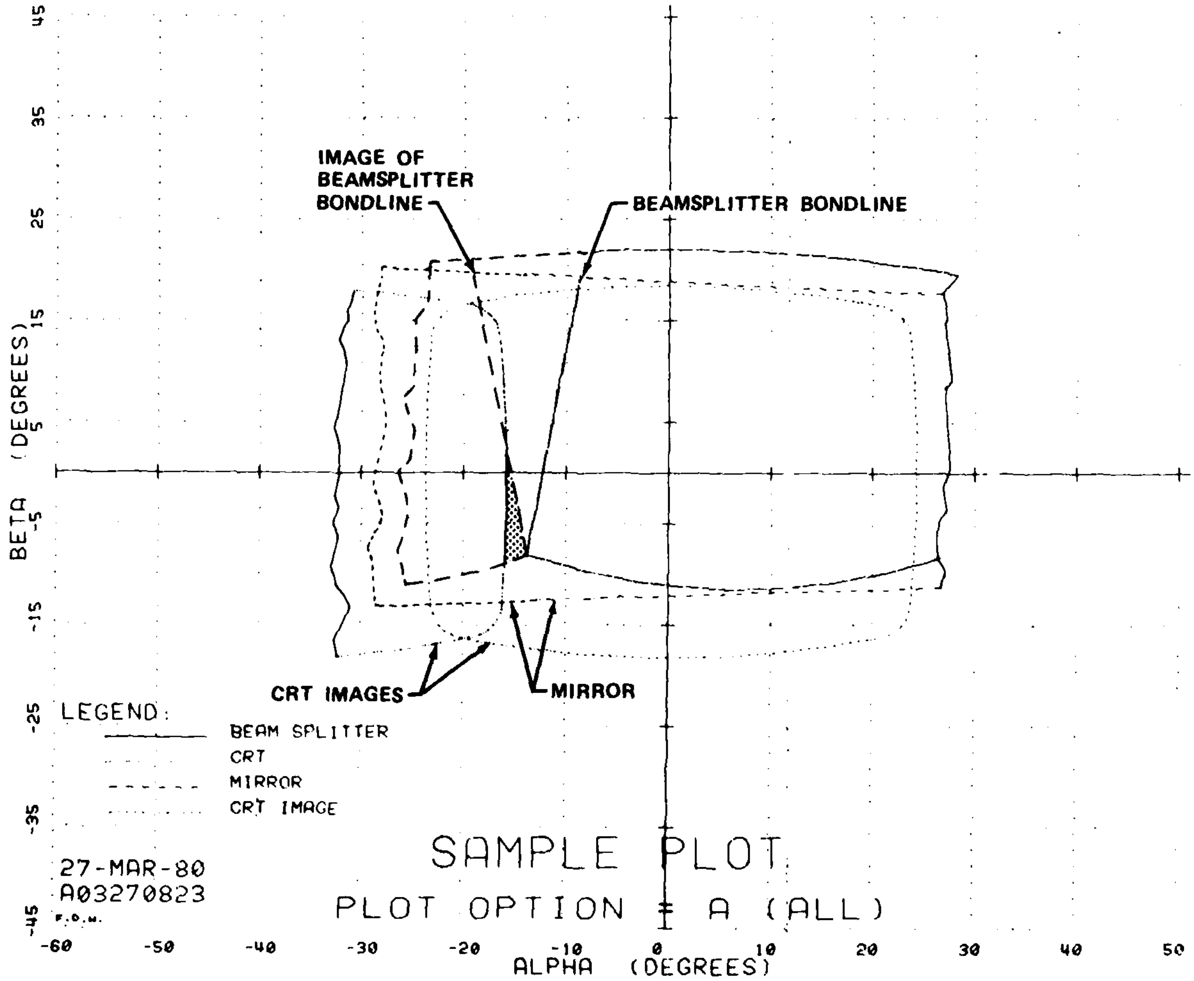


FIGURE 7. EFFECTS OF EXTREME HEAD MOTION ON ZERO GAP MODULES

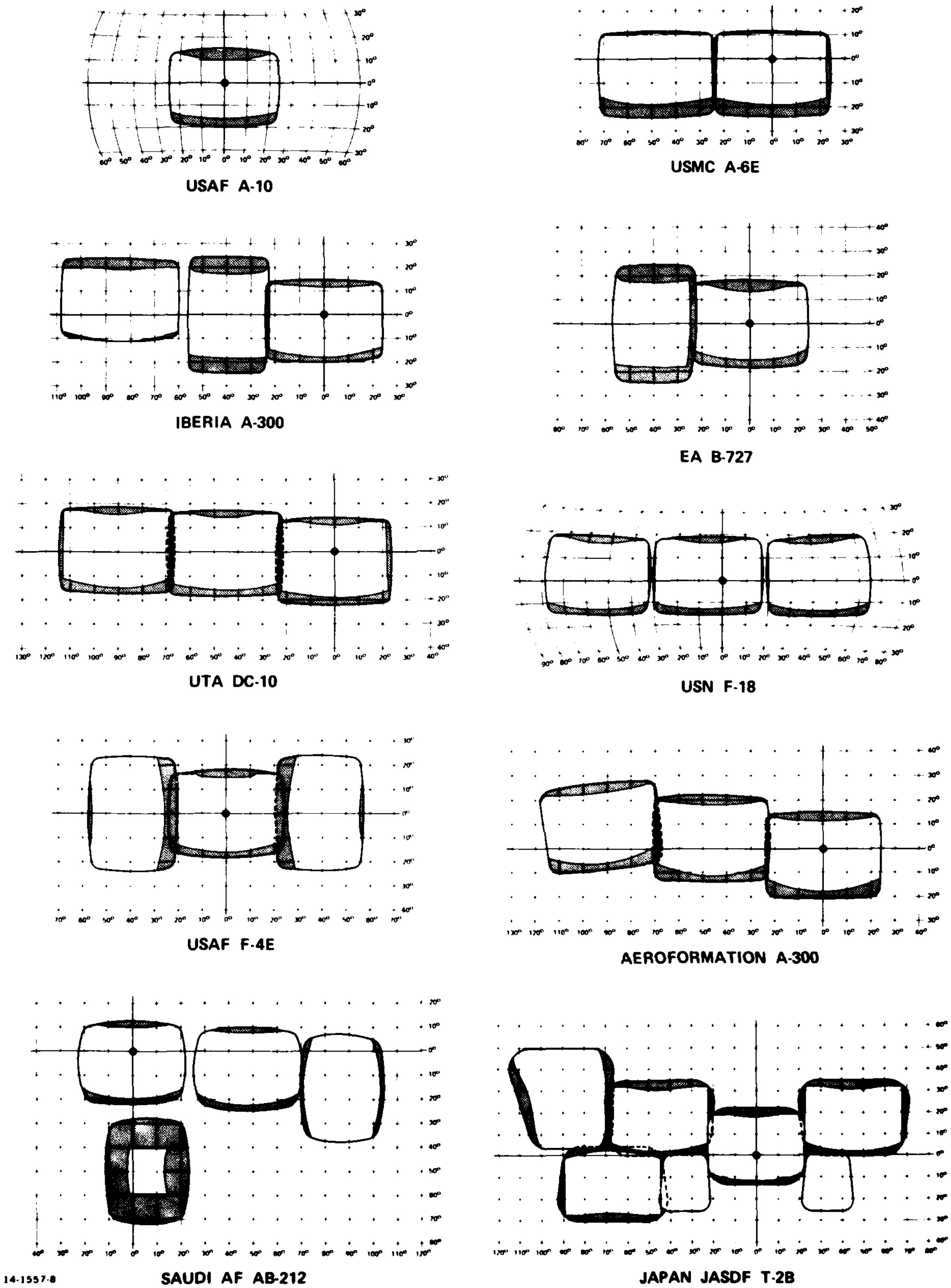


FIGURE 8. RECENT EXAMPLES OF VITAL IV CONFIGURATIONS

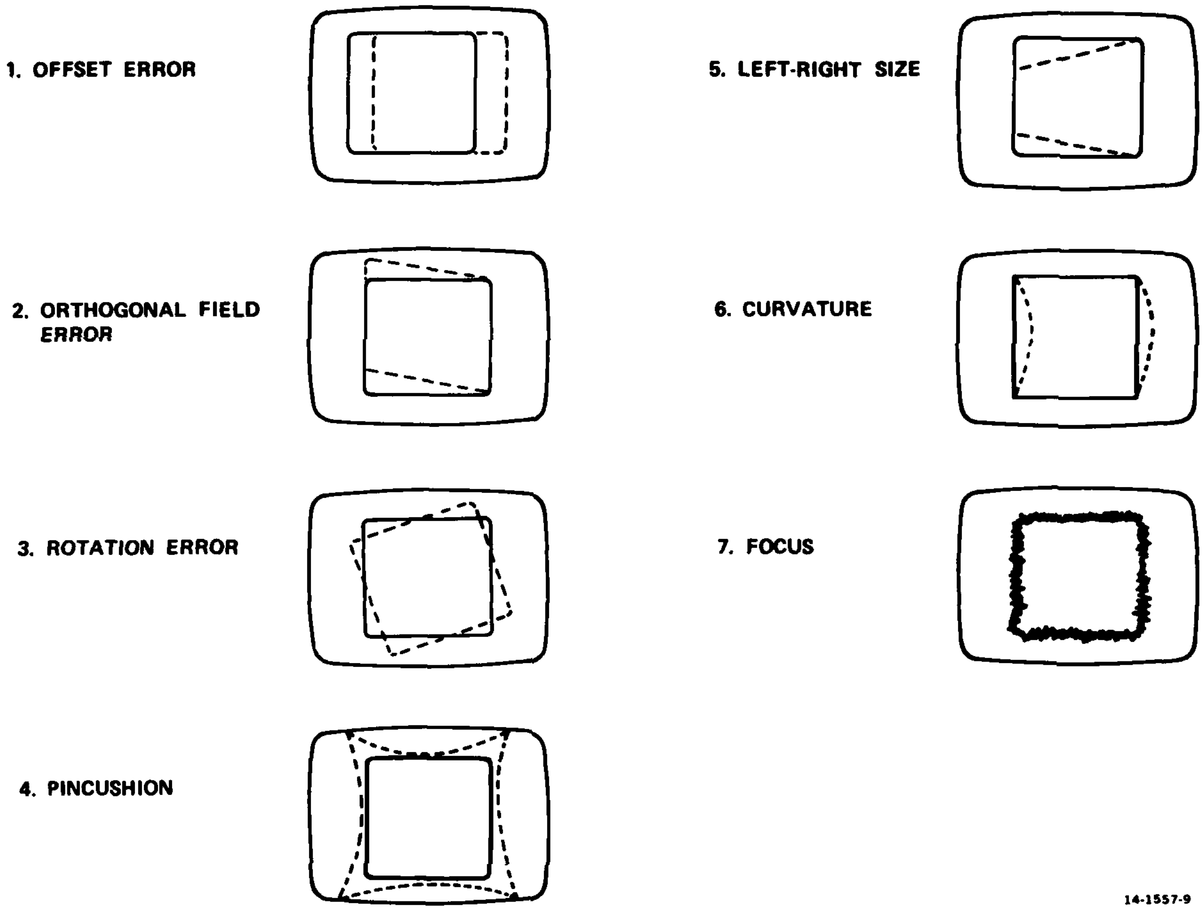


FIGURE 9. POTENTIAL CRT DEFLECTION ERRORS

The following photographs illustrate how well system distortion errors are controlled with today's technology.

## ABOUT THE AUTHOR

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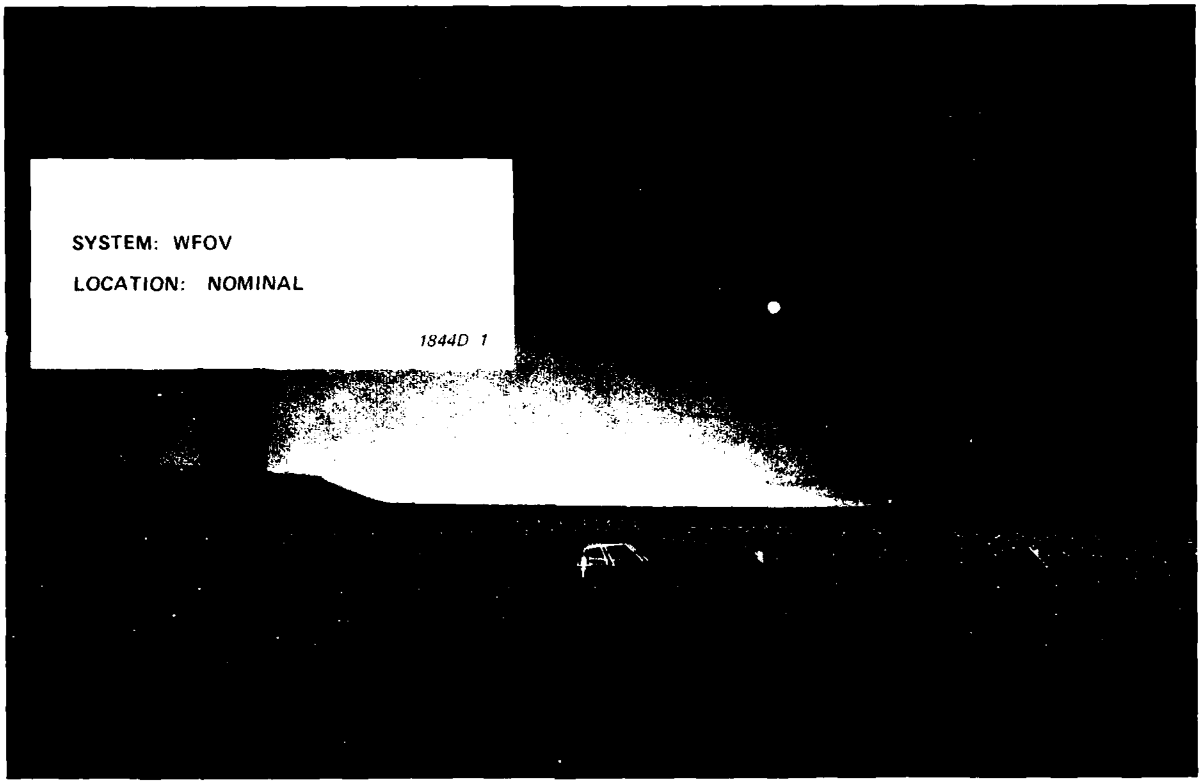
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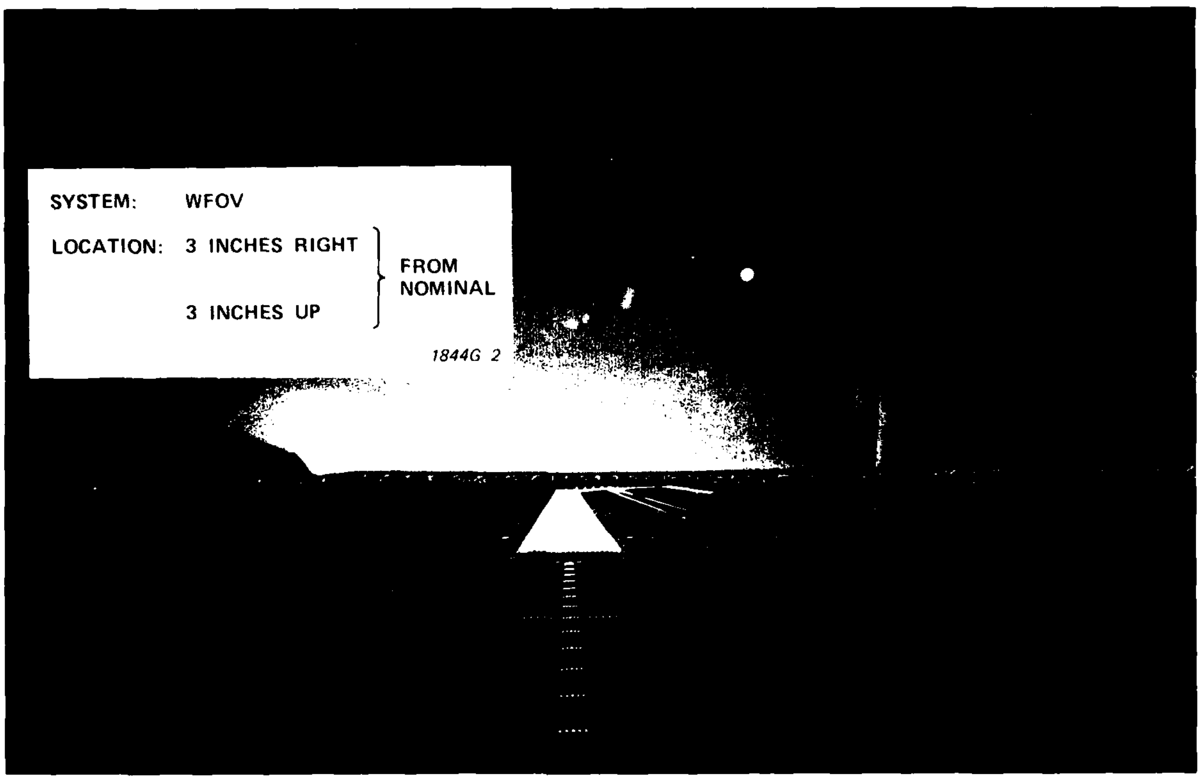
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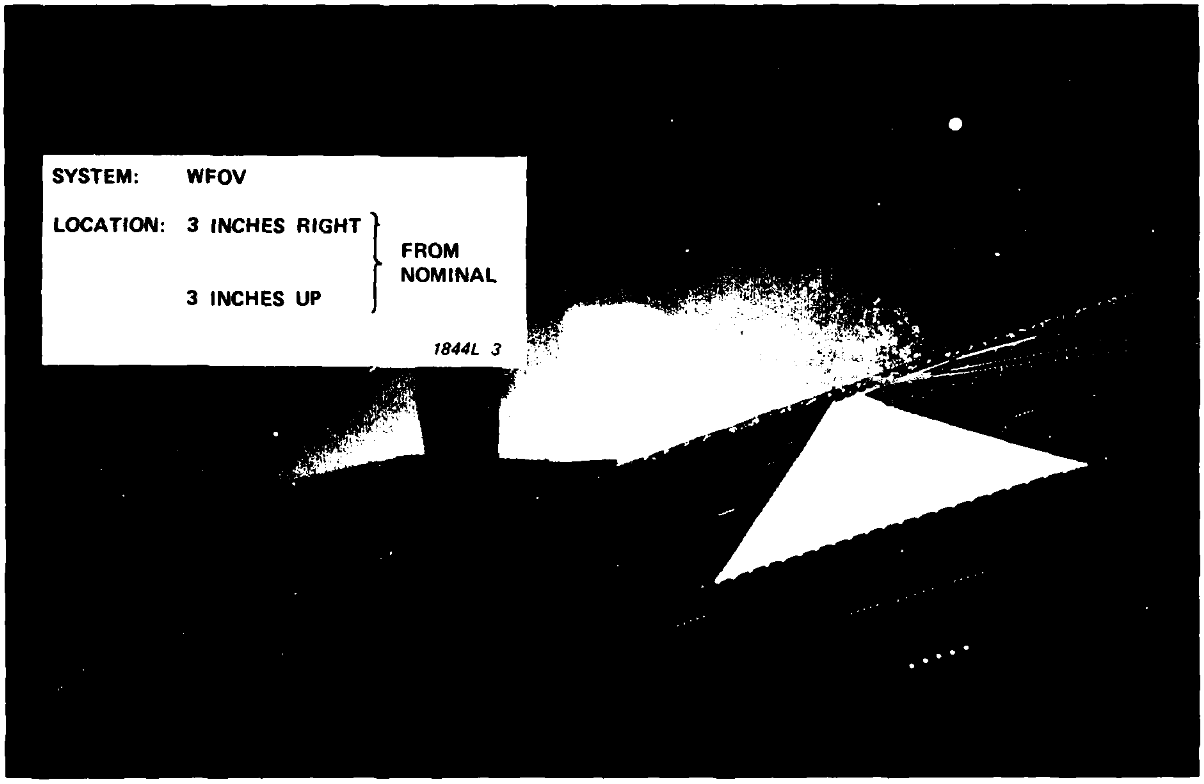
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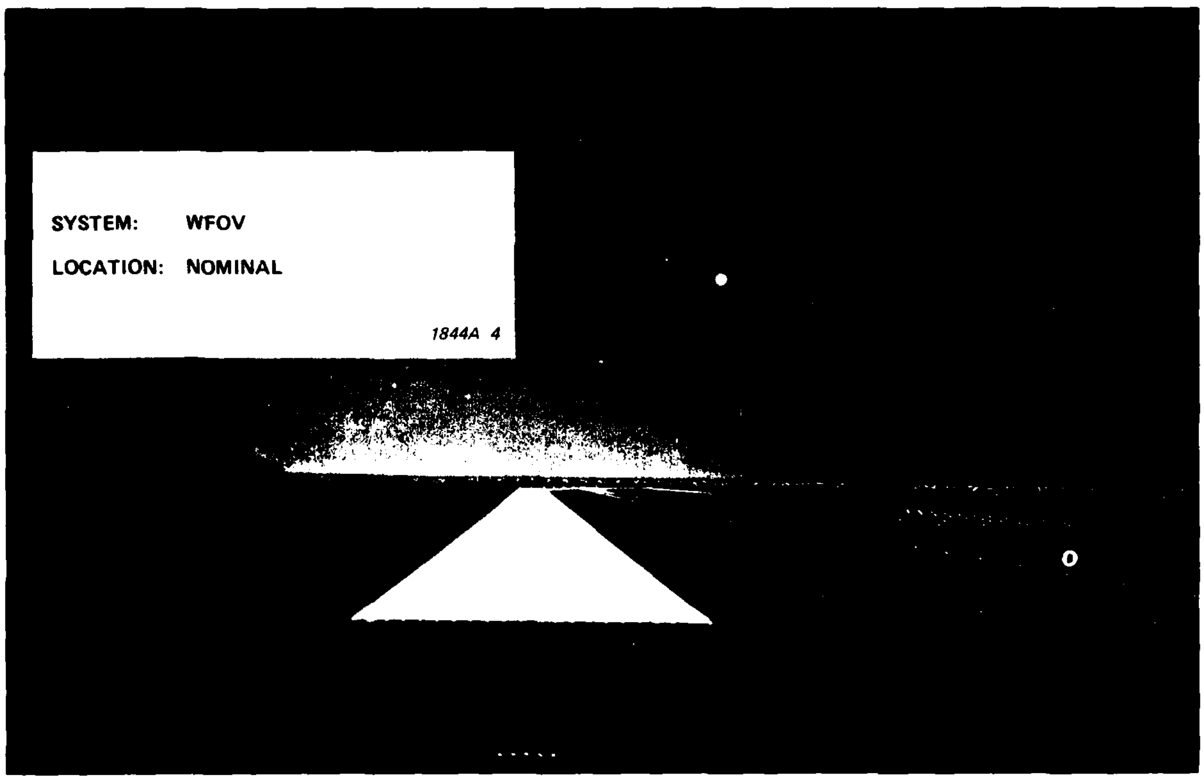
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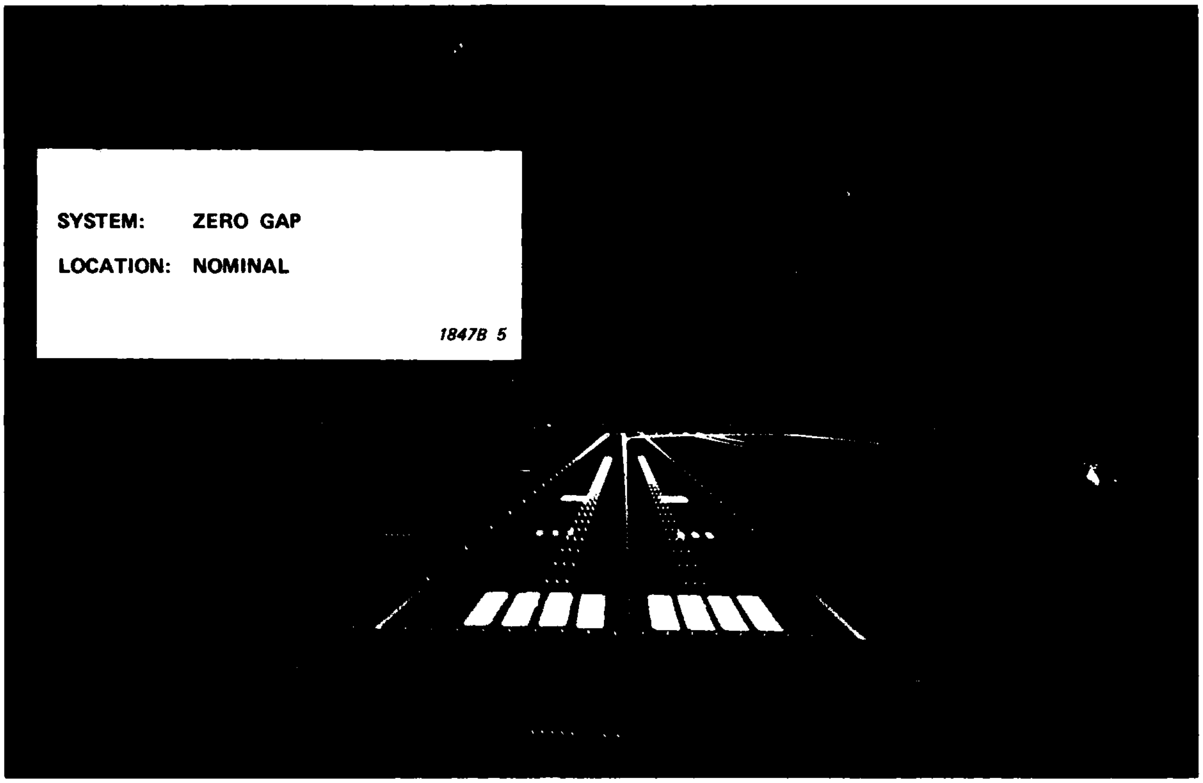
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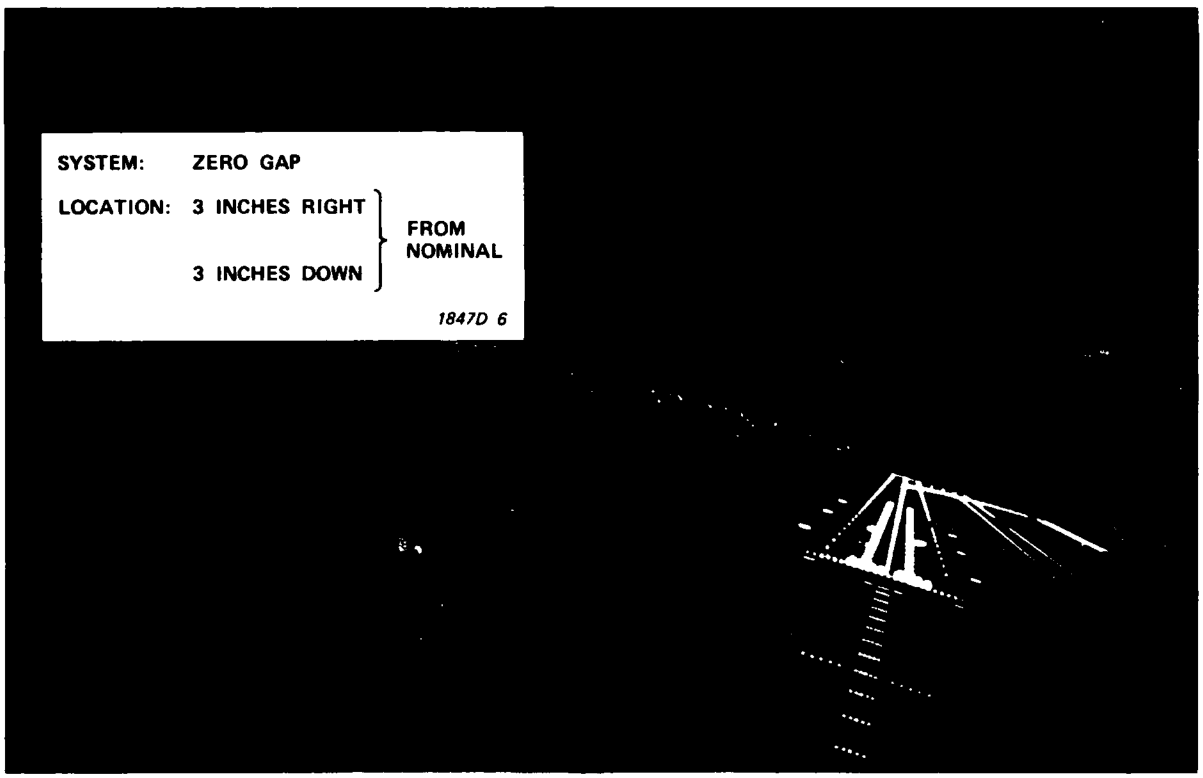
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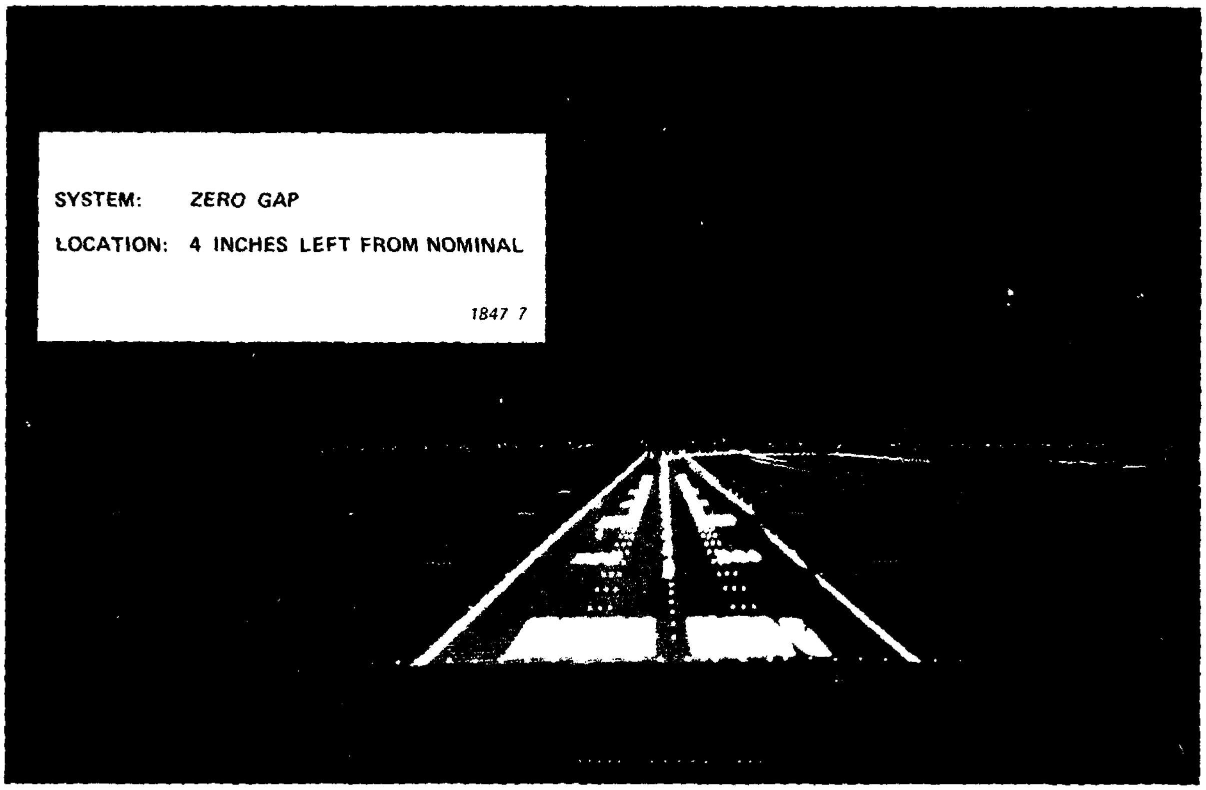
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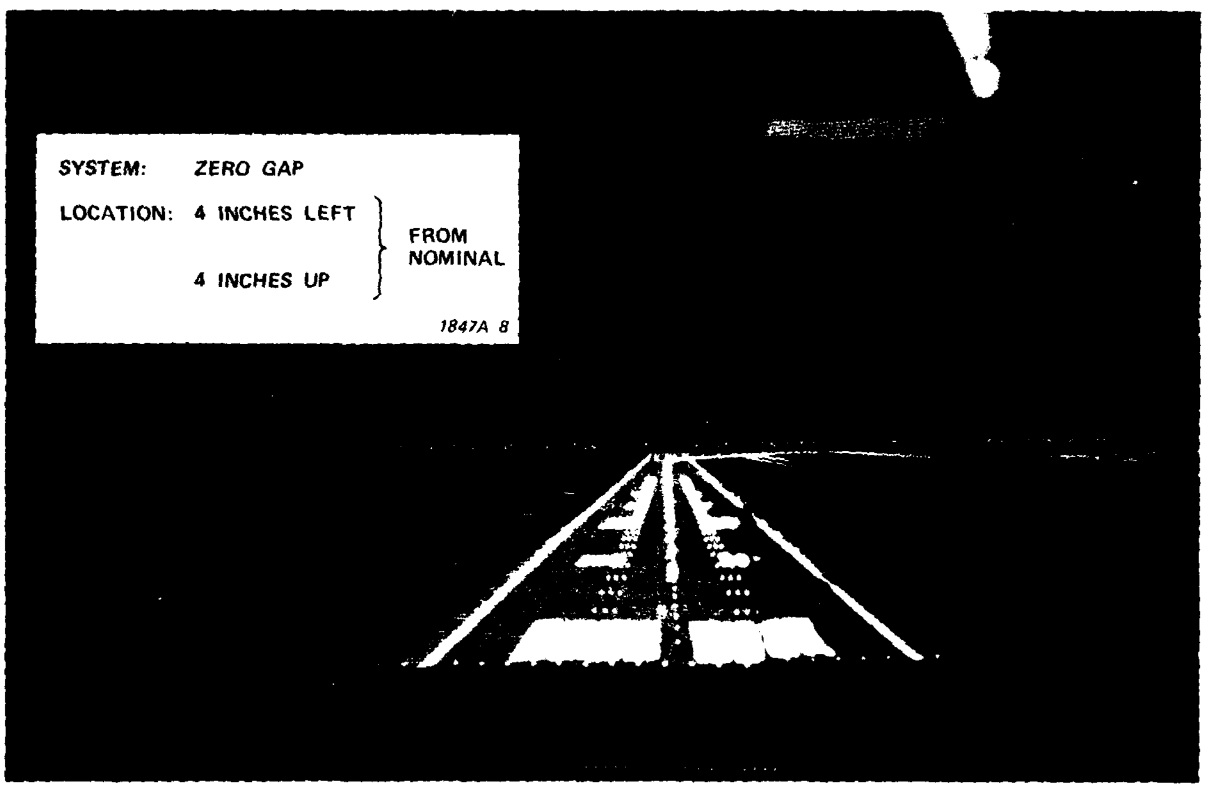
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HIGH OUTPUT - HIGH SPEED VIDEO IMAGES PROJECTOR
ADAPTED TO THE SIMULATION NEEDS

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ABSTRACT

The main specifications, for the visual displays associated with military aircraft simulators are first recalled ; they take into account the eye properties for spatial resolution, colour and speed of response. These specifications are examined from the point of view of simulator design and video-to-visual image converters. The features of a new projector developed by SODERN are then briefly described, and their adaptation to simulator needs are discussed.

THE SIMULATION NEEDS

During the first Interservice/Industry Training Equipment Conference, the lectures and discussions (1) have proven the importance of the simulation of visual stimuli on the training equipment efficiency ; the relative importance of the visual parameters of the display : resolution, colour... has been discussed.

For military aircraft simulators, the most demanding requirement is to cover more than three quarters of the full space (i.e. 10 steradians of solid angle) around the pilot with a high resolution image. The eye resolution capability decreases very fast with the angular distance to the foveal direction. At field center, in daylight level or photopic condition, the limit of visibility of a black disc on a clear uniform background corresponds to a 25 arc seconds diameter, i.e. 12 nsr (nanosteradians), but in the 6 sr eye field, the observer may see 1 million picture elements (pixels) only, which correspond to an average solid angle at 6 usr (microsteradians) each. The eyeball motion in the orbit, the head rotation capability, and the use of rear-view mirrors extend the use of the high resolution capability at eye field centre everywhere in the space around the observer. Therefore, the simulator demand for resolution is of the order of 10 sr/12 nsr = 830 millions of picture elements.

The image rate also is an important parameter : military scenes are usually fast moving ones, due either to the targets speed (ground vehicles, boats, aircrafts, rockets) or still more the angular motion of the trainee vehicle : for the display, the image angular motion to be reproduced may be of radians per second order of magnitude. From this point of view, the most critical difference between the natural scenes and their reproduction by cinematographic (movie or television) means is that the reproduced ones are time sampled : objects moving with respect to the reproduction frame have a jerky motion the eyes do not follow. We shall come back on this point. For moderate angular speed, the demand is to avoid the flicker effect which appears at image rates lower than 15 to 30 per second depending on duty cycle, light level and location in the field. Higher rates are recommended for long duration observations.

For the naked-eye observer, the image luminosity is characterized by the luminance of the light flow which reaches his eyes : colour vision, spatial resolution and in a lesser extent reaction speed to visual stimuli depend on this parameter :

- the effect on colour vision is well known : the change from the photopic colour vision to the scotopic colourless one occurs in the 10 to 0,01 lm.m-2.sr-1 (or 3 to 0,003 foot--Lambert) luminance range,
- the effect on spatial resolution is illustrated by figure 1 which gives the number of just resolved line pairs per radian in the eye foveal region versus the clear lines luminance (dark lines luminance = 0).

The visual characterization of the image is not limited to the spatial and time resolutions ; at a given time and for each pixel, the luminance and colour differential steps levels are also important parameters :

- the luminance dynamics should reach a range from e.g. 100 to 1, with a minimum of 64 steps (6 bits or a maximum of 7% average difference from step to step),
- the reproduced colours range should cover most of the natural colours. The

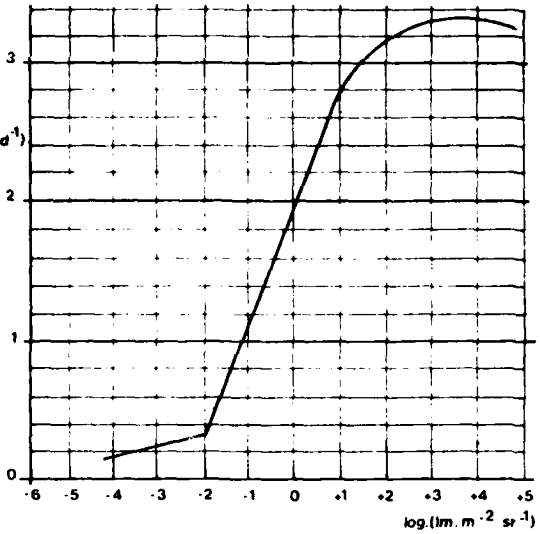


Figure 1
Reciprocal R of the line pairs period of a black and white periodical pattern just resolved by human eyes, as a function of white lines luminance L.

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National Television Standards Committee (NTSC) conventional range selected for the broadcast TV (fig. 2) covers about 45 % of the discernable colours at photopic luminance levels (and a much higher percentage of natural ones). For a given luminance level, about 2500 different colours may be recognized, thus about 1000 in the NTSC range, this corresponds to a 10 bits chrominance range ; a 8 bits chrominance discrimination could probably be sufficent.

Assuming 830 million pixels per field, 30 fields per second, 6 bits luminance range and 8 bits chrominance, the visual display input rate should be 3.5.10 to the 11th bits per second.

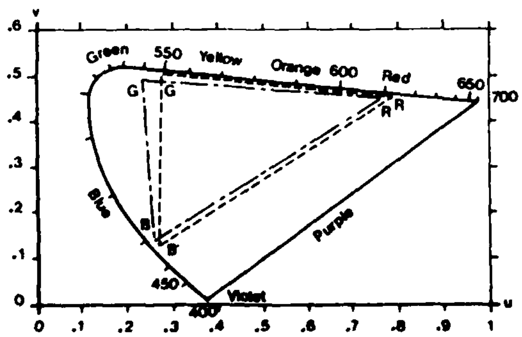


Figure 2
Uniform chromaticity plane, NTSC conventional triangle (RGB) and colour range as reproduced by the three light valves SODERN projector (R'G'B').

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THE SIMULATORS CAPABILITY

The capabilities of real simulators are limited by technology and cost : trade-offs have to be found to produce the most acceptable images taking into account the characteristics of the available technologies and the relative importance of the image qualities which have been described in the previous chapters.

Trainee head motion allowance and particularly the displays for two or three people team require large optical extent (product of the front area of visibility by the field angle). For wide field angles, two families of displays are used:

- real image displays where the trainee heads are close from the center of a large hollow sphere or dome on the inner wall of which a mosaïc of images is projected,
- virtual image displays where the trainee head is close of the center of a dodecahedron of joining wide field optics (pancake windows*) at the front focal surface of which are produced the real image of the local field.

For the same requirement at the trainee level, both designs do not demand the same performances from the optical image generator : luminous output, field angle, subraster capability,.... The aim of this paper is not to compare these designs, but to analyze the adaptability of the video-to-optical image converters to their needs.

The wide field dome displays require high output image generators ; due to the multiple reflection inside the dome, a trade-off has to be made between sphere diameter, scene luminance and sphere contrast losses when the projector output is limited. Virtual image displays introduce geometrical implantation constraints which make of great interest the introduction of subraster capabilities,... We shall not go in futher details, the above ones were only to show the interaction between the display design and the video-to-visual image converter capabilities.

These last capabilities are limited by the physical phenomena used for the image conversion. Competing solutions use :
- cathode ray tubes in which the spatially modulated light is produced by a single component : this solution is limited in luminous output, colour range (for a single tube) and screen size. Spatial resolution may be high,

(* a trade-mark of Farrand Optical Company).

- equipment in which the light is produced and modulated by separate components ; three types of light modulators (or light valves) are now developed :
  - using refraction or diffraction by oil films,
  - using polarization in solid crystals,
  - using polarization in liquid crystals,

  all able of much higher output, with limited resolution capability and different time dependent characteristics.

Presently, the spatial resolution of the light valves is limited to about 1 million pixels per frame, thus the use of a mosaïc of e.g. 10 images each covering 1 steradian field is usually accepted : the corresponding 1 usr pixel size (4,5 arc minute disc diameter) is to be compared to the 12 nsr wish : artifices are to be found to enhance the spatial resolution in the field where it is really needed.

It is known that for a given spatial resolution in complex scenes, the detection and identification capabilities are increased when luminance levels (grey shades) and colour data are present : this increases the favour of colour displays when spatial resolution needs can not be fully satisfied.

The video-to-visual image converters time behaviour is also an important feature : the time distribution of the light in a frame period. Too small of a duty cycle increases the flicker effect. If the image erasing time is too long, the image becomes laggy, smearing details in moving scenes, a very important fact in simulation.

## THE SODERN VIDEO IMAGE PROJECTOR

The SODERN video-to-visual image converter is of the light valve type (2), it uses a white light xenon arc as light source, and electron beam addressed light valves using polarization in a solid crystal (more details about light valve and projector operation in annex). The images produced by this type of modulator are characterized b:
- large luminous flux control capability (more than 2500 lumens),
- large pixels rate capability (more than 3,5.10 the 7th per second),
- neither flicker nor lag (simultaneous erasing and writing),
- image storage time capability up to minutes,
- subraster capability,
- flat image (no apparent line structure),
- large distortion correction capability (scanning rates),
- random access capability.

Light valves and projectors using this principle have been manufactured at laboratory scale during the years 1976-77 for interactive cable television experiments in large movie theaters. The main characteristics of this equipment are discussed in annex 1. This equipment has been put in operation many times in various places since their manufacture, and are still in operation with their original light valves: they have proven to be reliable, with low maintenance and adjustment. Most of the above mentioned image features have been demonstrated*.

The development of a version adapted to the simulation and data display is now in progress, partly supported by US and French Government agencies. This development takes into account of the most common requirements, for functional, interface and environmental specifications, but also for availability, maintenability and life cycle cost points of view. In this development work, the emphasis is put on the improvement of the resolution since it is the most critical performance for the contemplated applications. From our point of view, the unconventional features of the images produced by this type of light valve give new possibilities for the optimization of the image generation system, which are not fully explored.

* a movie illustrating the main image features (absence of flicker, absence of lag, image flatness, resolution, storage capability) is presented at the Conference.

## Annex

### THE SODERN VIDEO IMAGE PROJECTOR PRINCIPLE AND CHARACTERISTICS

*The schematic diagram of the equipment is* represented by figure 3.

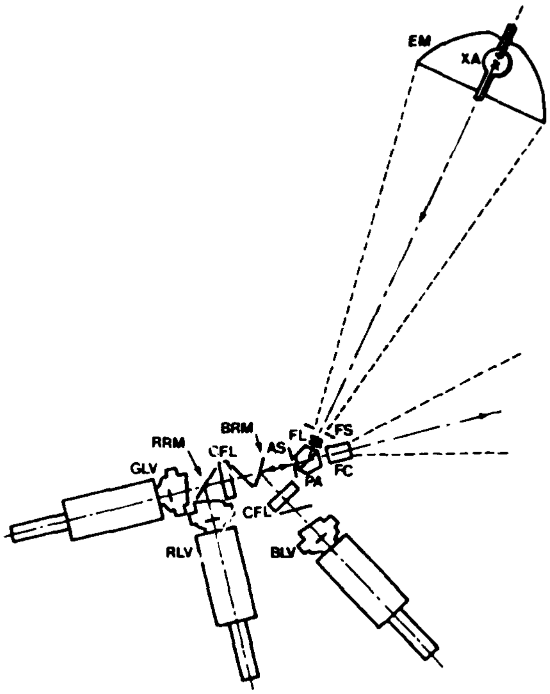


Figure 3
SODERN light valve projector structure (schematic).
AS = aperture stop, BLV = blue channel light valve, BRM = *blue reflecting mir*ror, CFL= collimating-focusing lens, EM= ellipsoïdal mirror, FC = focus converter, FL = field lens, FS = field stop, GLV = green channel light valve, PA = polar*izer-analyzer*, RLV = red channel light valve, RRM = red reflecting mirror, XA = xenon arc.

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The light produced by a xenon arc is collected and concentrated by an elliptical *mirror on a field stop. An image of this* field stop is focused by a set of lenses and through a polarizer on the electro--optical target of three light valves. An aperture stop is located at the *polarizer exit and at the front focus of* collimating-focusing lenses. The white beam is split in three spectral bands, the blue, green and red light beams reflected back by the three light valves are recombined and then cross-back the polarizer which is now used as an analyz*er. The target of the light valve behaves* as a birefringent plane mirror, the local birefringence of which is electrically modulated according to the video signal. The collimating-focusing lenses are used to focus the targets image onto the screen. This combination of locally modulated birefringence, polarizers and focusing optics provides an intensity modulated image onto the screen for each *channel. Due to use of a single exit pu*pil, the registration of the three superimposed colour image components is not affected by the shape and position of the screen.

In order to understand the features of the images produced by the light valve it is necessary to say few words about the light valve target operation (figure 4).

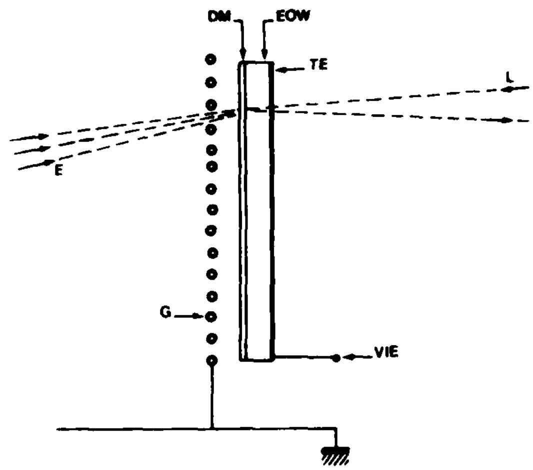


Figure 4
Titus light valve electro-optical target structure and mode of operation. DM = dielectric mirror, E = electrons, EOW = *electro-optical* wafer, G = grid, L = light, Te = transparent electrode, VIE = video input electrode.

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The electro-optical *component of* this target is a thin (0,2 mm) wafer of a transparent dielectric crystal the birefringence of which, in the direction perpendicular to the plane faces, depends on the electrical field applied in this direction (longitudinal Pockels effect). The illuminated face (right side on the figure) is coated with a transparent and conductive layer used as input electrode for the video signal. The opposite face (left side) has received a set of alter*nate low-high refractive index dielectric* layers which behaves as a mirror. The outer surface of this mirror is scanned by a constant voltage electron beam ; the design of the electron tube part of the *light valve is such as this electron beam* may remove as well as to supply electrons up to give the surface the same voltage as the constant voltage of a grid placed nearby.

If the electron beam current is high enough to supply the target with all the electrical charge per unit area corresponding to the product of the target capacity by the peak video voltage, when scanning the target surface the electron beam replaces the previous charge status by a new one corresponding to the instantaneous video voltage. As the target and the mirror are made of good dielectric materials, the charge remains unchanged up to the new scanning : this explains :
- the target image storage capability and
- the absence of flicker and of lag.

The local target polarization property is voltage controlled : as far as the electron beam current density is high enough, when the video voltage is transferred through the target the supplied extra charges are rejected : this explains :
- the image flatness without resolution loss and
- the absence of influence of the electron beam scanning speed on the luminous output.

The combination of the two above described facts explains also why parts only of the image can be refreshed (subraster and calligraphic modes).

The equipment manufactured in 1976-77 has been designed to fit the European broadcast standards :
- 25 images per second (50 frames, double interlace),
- 625 lines per frame,
- 650 pixels per line at modulation transfer factor (MTF) = 5 %,

The colour reproduction range is determined by the dichroïc beam splitter cut off wave lengths :
- red channel : 595 to 660 nm,
- green : 515 to 575 nm,
- blue : 440 to 490 nm,

these primaries are represented in the constant chromaticity plane, figure 2.
The luminous output for a all white image reaches 2700 lumens, the dynamic range (all clear/all dark fields output) reaches 60/1.
Local deviation of illuminance and colour in the field are well inside the professional movie specification.

The new light valves (manufactured in the frame of a contract directed by USAF through General Electric) give now 20 % FTM at 650 pixels per line.

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BEHAVIORAL BASES FOR DETERMINING VEHICLE DETAILING IN SIMULATION DISPLAYS

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ABSTRACT

Effective representation of armored vehicles in simulation displays demands a careful evaluation of human perceptual capabilities. This holds especially true for computer generated target displays, which must provide sufficient detail to allow vehicle identification within limitations of computer processing time and display resolution. Even in image generation and display systems not incurring such limitations, the image detail need not exceed human perceptual and cognitive information processing capabilities. Providing excessive detailing of targets may, in fact, produce negative training by allowing those being trained to depend on information unavilable in combat for target identification. Results of research manipulating visible target detail in target identification training and its implications for target displays are discussed. Estimates are presented for the visibility of features of threat and friendly main battle tanks, based on analysis of past empirical research done under ideal visibility conditions and visibility data from past research.

## INTRODUCTION

Picture yourself as a Tank Commander, moving in column along a road toward your forward battle position. Suddenly, you detect two tracked vehicles moving along a treeline about 2000 meters away. Do you engage them, or don't you? You have only split seconds to decide. If they are friendly and either simply lost or moving to a position near yours, engaging them would result in the death of US soldiers or your allies. If they are enemy, failing to engage them endangers your life, the lives of your men, and your tank. Are they friend or foe? This question will recur frequently given the fluid and "dirty" battlefield expected in most future European scenarios.

The situation described above clearly points out the need for effective target identification training. Simulation offers exciting opportunities for training many aspects of combat performance, including target identification, since it affords the capability to present a wide variety of realistic targets in highly realistic tactical settings. Troops can be trained to identify targets within the normal context of maneuver and combat engagement. However, the capability to train target identification as a matter of course raises the question of how much detail computer-generated vehicle representations or other target displays require to allow realistic target identification. The detail must be sufficient to represent a vehicle's critical features (those that differentiate it from other, similar vehicles), but the display should not represent features that would be unavailable in a combat setting and at the ranges a target would normally be identified. The danger with highly detailed representations is that troops might learn to depend on target details that are simply unavailable for target identification in combat.

## METHOD

The US Army Research Institute (ARI) field unit at Fort Knox approached the target representation problem for tank gunnery by examining observers' performance in learning to identify slides of tank targets at different ranges, both before and after an experimental ARI target identification training program (see reference 2). Simulated training and test ranges of 4000 and 2000 meters through the 8x sight of the M60A1 were selected, because these two ranges encompass the ranges in which tank target identification would normally take place, assuming good visibility conditions and making two other reasonable assumptions. The first assumption is that few targets in a tactical setting will be detected beyond 4000m (with the exception of large armor formations, in which case target identification is a different task than for individual vehicles), and the second is that an enemy should be identified at a range of 2000m or more, given the engagement hit probabilities given in FM 71-1 (1). Examining observers' ability to learn target identification at these two ranges allows one to determine how much of a difference, if any, in target identification training occurs due to reduced visibility of target features at the farther compared to the nearer range. From these data one can infer the detail needed in displays to train target identification at ranges demanded in combat.

### Subjects

Twenty OSUT (One Station Unit Training) armor crewmen (10 gunner/loaders and 10 drivers) served as observers. All had completed the standard block of instruction on Soviet Soldiers and Equipment, which includes basic target identification training, prior to the experimental target identification training program received as a part of this research. In this paper, however, references to training refer to training received through the experimental training program administered to subjects in this research.

### Stimuli and Apparatus

Targets for training and tests of observers' learning were presented via slides. Slides of vehicles were taken from the ARI Combat Vehicle Identification (CVI) Program (2), as were the verbal descriptions of the vehicles that were presented during the training program. The training program itself was a modified version of one module of the ARI Combat Vehicle Identification Program, and lasted approximately two to two and one-half hours. Seven tanks were selected for training and testing, with the rationale that, first, tanks are the primary targets for tanks on the battlefield, and second, that they are highly confusable combat vehicles and therefore present some of the most difficult discriminations to be made in target identification in combat. The seven tanks used were the Soviet T-55, T-62, and T-72, the French AMX30, the US M60A1, the West German Leopard I, and the British Chieftain. The slides showed model vehicles on a terrain board. All vehicles were photographed on the same spot on the terrain board, and all vehicles were camouflage painted. These measures prevented observers from learning to identify vehicles based on extraneous cues from the terrain or vehicle markings. Frontal, flank, and oblique views of all vehicles were included. Slides of vehicles were rear-projected by a Kodak Ektagraphic slide projector, Model AF-1. Exposures of slides were timed by a hand-held stopwatch.

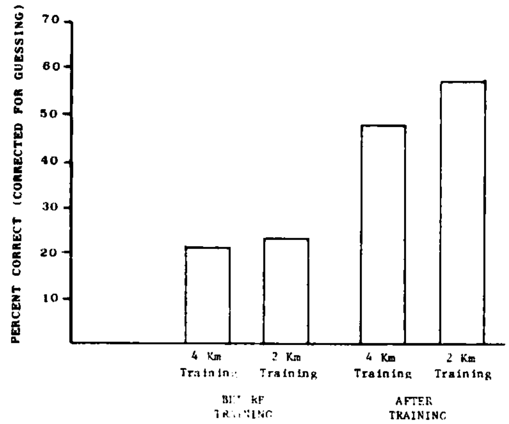


Figure 1. PERFORMANCE IMPROVEMENT WITH ARI COMBAT VEHICLE IDENTIFICATION PROGRAM

Procedure

Observers were tested and trained in groups of ten. Within each group of ten, five observers were selected to receive the experimental target identification training program at a simulated range of 2000m; the other five observers received the training program at a simulated range of 4000m. Ranges were simulated by seating the observers at different distances from the screen upon which slides were projected at a constant scale (for more detail see the instructions and discussion accompanying the CVI package). Five gunner/loaders received training at 2000m, and five at 4000m; the same held true for the drivers.

Before undergoing the experimental training program, each observer was given two tests (without feedback) on all views of all vehicles, with one pretest at each of the two ranges. Presentation of the slides of all seven vehicles in each of three views was randomized for each pretest. Each slide in each of the 21-item pretests was presented for ten seconds and followed by a ten second period with a blank screen to allow the observers more time to write down their answers. After the pretests, the vehicle identification program was presented. This program included verbal descriptions of vehicles accompanying the slides of the models, as well as slides of vehicles that observers were asked to name, and for which feedback was given following their responses. Specific details of the training program are presented in an ARI Report currently in preparation. After the instruction, all observers were given two final tests, with one test at 2000m and one at 4000m. As with the pretests, order of presentation was randomized over all vehicles and all views on both tests.

RESULTS AND DISCUSSION

Analysis of variance was applied to the number of correct vehicle identifications (corrected for guessing). The analysis revealed that performance improved significantly after the experimental training program ($p<.01$). Figure 1 shows this effect graphically in terms of percent correct, corrected for guessing. The difference between performance at simulated ranges of 2000m and 4000m was not statistically reliable either before or after subjects received the experimental training program. Similarly, the difference between observers trained at 2000m and those trained at 4000m was insignificant, as was the interaction between training range and test range. The above results show that first, the ARI Combat Vehicle Identification Program raises target identification performance significantly over that provided by Armor OSUT training, regardless of some variation in training and testing range, and second, that there is still more room for improvement.

The analysis also showed that performance differed for different vehicle orientations ($p<.01$). Figure 2 shows this effect graphically, with results

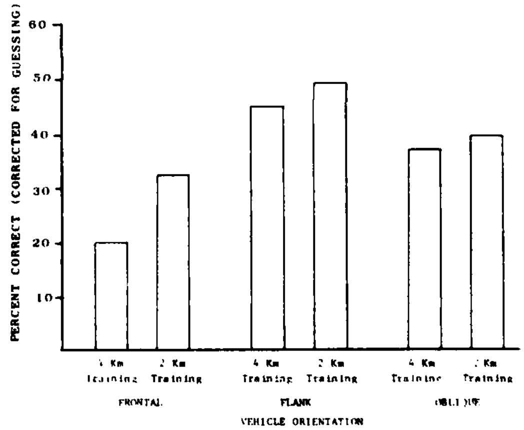


Figure 2. PERFORMANCE DIFFERENCES FOR DIFFERENT VEHICLE ORIENTATIONS

before and after the experimental training program combined. One must qualify statements about this effect, however, due to a significant interaction of vehicle orientation with training. Figure 3 shows this interaction. A test of simple main effects revealed first, that performance after training improved significantly over that before training for all three vehicle orientations ($p<.01$ in all three cases), and second, that performance differences among different vehicle views were significant only after training ($p<.01$). Pairwise comparisons using Tukey's HSD revealed that after training, observers identified flank views of vehicles significantly better than both frontal views ($p<.01$)

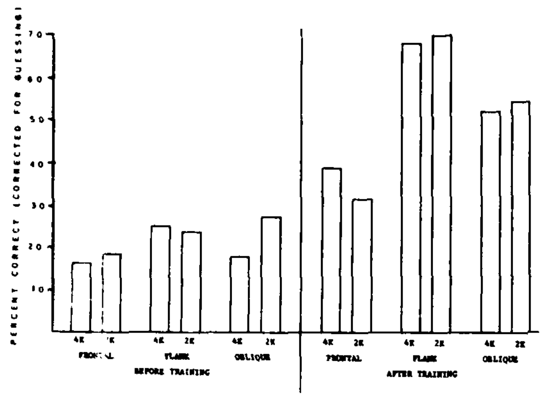


Figure 3. PERFORMANCE DIFFERENCES FOR DIFFERENT VEHICLE ORIENTATIONS BEFORE AND AFTER TRAINING

and oblique views ($p<.01$). These comparisons simply show that subjects in the present research learned the most about identifying flank views of vehicles, and the least about identifying frontal views of vehicles. The performance differences between different vehicle orientations simply reflects the differences in the number of critical features available in the three views. Training observers to identify frontal and oblique vehicles present a particular challenge for future target identification training research, since the tendency to fire at another vehicle without making a positive identification first will be greatest for vehicles in those orientations.

The striking aspect of these results is that, within practical limits, the effects of the range at which observers were trained and tested, as well as the interaction of these two factors, were extremely small relative to the large improvement of all observers over training, and were not even reliable enough to approach statistical significance. This implies that, for all practical purposes, observers learned to identify targets just as well with the details that could be seen at 4000m through an 8x sight as they could with the details that could be seen at 2000m through an 8x sight. Therefore, when considering training observers to identify tank targets through the 8x M60A1 sight under ideal visibility conditions, one need not have as much detail as can be seen normally at 2000m, although including that much detail will not harm training.

One might wonder why insignificant effects of training and test range were found in the above research. This question can be answered by first considering data collected by Foskett, et al. (4) on the detectability of features of armored vehicles. Figure 4, taken from their report, shows the detectabilities of the features they investigated. Consider that ranges of 2000 and 4000 meters through an 8x sight correspond approximately to 250 and 500m with unaided vision if the atmosphere is perfectly clear. One can see by Figure 4 that there is only a small difference between the detectability of features at 250 and 500 meters with unaided vision. Small features, such as the number of roadwheels (if the number is large) become dramatically less detectable over this increase in range, but the probability of detecting the largest features drops very little. Coupling this relatively small difference in detectability with the poor performance before training and the fact that the ARI program emphasizes identification using large, highly noticeable features (while de-emphasizing the importance of small features) it is probably not surprising that the effects of training or test range were insignificant.

In considering the results of the above research, however, there is a very definite caveat. Both our research and the research of Foskett et al. were conducted under scaled conditions. Hence, they apply specifically to an atmosphere of almost infinite visibility and do not consider effects of atmospheric attenuation. The results of the research reported here are an overestimate of the actual detectability of vehicle features in a normal outdoor environment. The impact of various levels of atmospheric attenuation on actual detection of armored vehicle features is yet to be thoroughly investigated. However, one can develop a crude estimate of the effects of atmospheric attenuation through data such as those presented by Middleton (5). Middleton presented a series of nomograms allowing one to predict the 95 percent detection level of objects of various sizes, given certain levels of background luminance, the target to background contrast prior to contrast extinction by the atmosphere, and meteorological range (that range at which atmospheric attenuation reduces target to background contrast to threshold). The data Middleton presented allows one to generate curves, such as those in Figure 5, from which one can estimate the amount of drop in visibility of a feature with reduced lighting and reduced meteorological range. For more detail on the derivation of Figure 5, the interested reader is referred to a forthcoming ARI Working Paper dealing with vehicle feature detectability (6). If one assumes that these curves can be considered a "pure" reduction in visibility, disregarding any interactions of visibility reduction with target background, one can rescale the abscissa of Figure 4 to reflect a certain proportion of drop in detection range. An example of this rescaling, showing the impact of reduced visibility and a reduced light level on the detection data of Foskett et al. is shown in Figure 6. It is, of course, only a very rough estimate, and actual likelihoods of detection in a tactical setting depend on a number of factors, including such things as the target background and observers' criteria.

One can see from Figure 6 that under very hazy and overcast conditions, features become much more difficult to see. Only gross features such as whether a vehicle is tracked or wheeled, whether or not it has fender skirts, its main gun, its turret position, and turret shape are readily available. Any difference in target identification at 4000m and 2000m under these conditions is yet to be determined. For a further discussion of the impact of atmospheric conditions on feature visibility, the interested reader is again referred to the forthcoming ARI paper on feature visibility (6).

What conclusions can be drawn from the research reported here? Since the lethality of modern weapons may easily make 2000m the minimum range by which an enemy tank must be identified under good viewing conditions, it seems impractical to conduct target identification training with a final goal of training people to identify tanks only within 2000 meters. Therefore, for practical purposes it seems

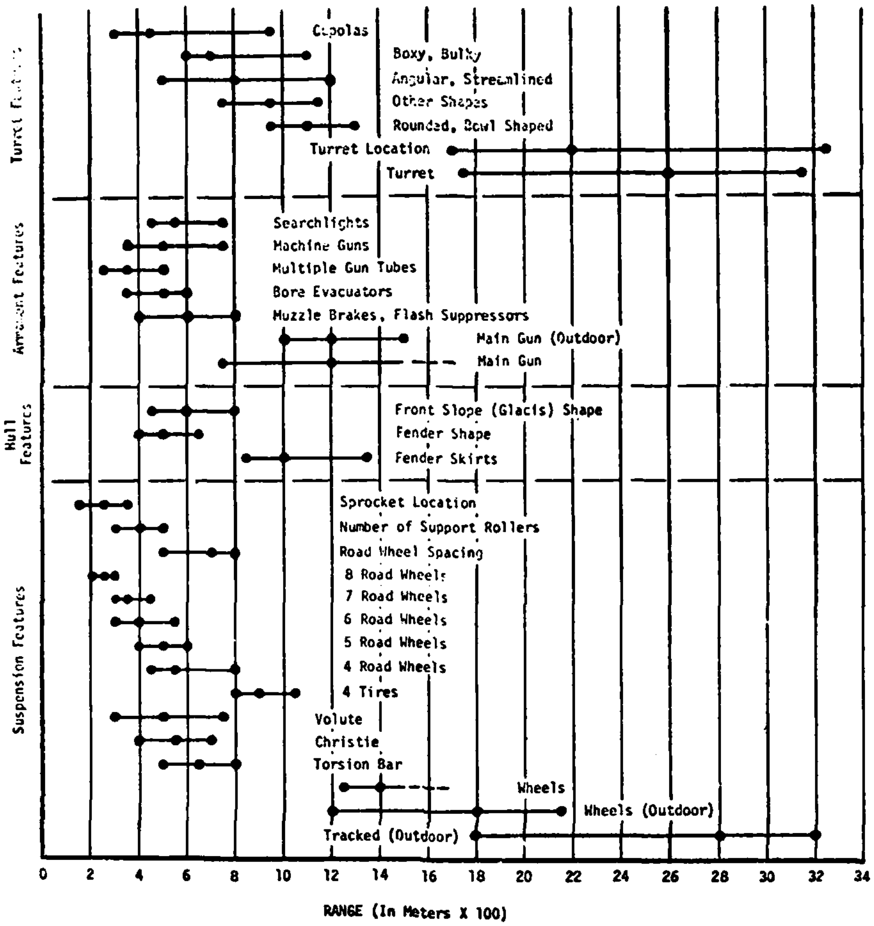


Figure 4. DETECTION RANGES FOR SELECTED VEHICLE FEATURES (FIGURE FROM FOSKETT, BALDWIN, AND KUBALA, 1978)

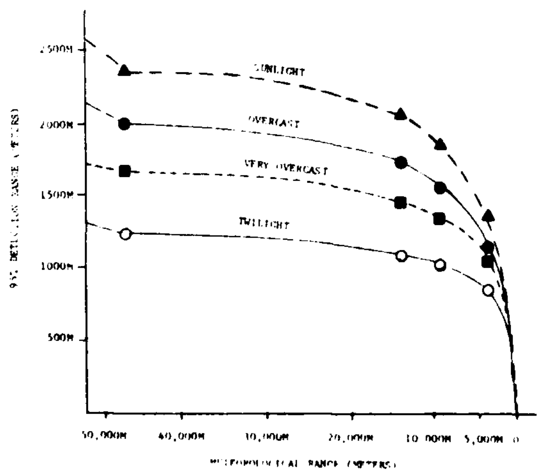


Figure 5. DETECTION RANGE AS A FUNCTION OF METEOROLOGICAL RANGE FOR CIRCULAR TARGET (AREA = 1 SQ. FT.) AGAINST SKY BACKGROUND. CURVES FIT BY HAND.

unnecessary to train target identification with more details than would be visible under ideal viewing conditions through an 8x sight at 2000m. Additionally, since any difference between target identification training at 2000 and 4000m proved to be small relative to other influences in the present research, only those that can be seen at 4000 meters with an 8x sight are necessary to include for practical training purposes. Since this research did not address training with even fewer features than those available at 4000 meters are necessary for reliable identification, until further research is conducted.

Several questions yet remain to be answered that may have an impact on future target identification training programs. What is the impact of including more features than are available at 2000m? Is it feasible to consider beginning target identification training with highly detailed vehicle representations, and systematically reduce the detailing until vehicles can be identified based on minimal information? Finally, a better understanding of the impact of time constraints during target

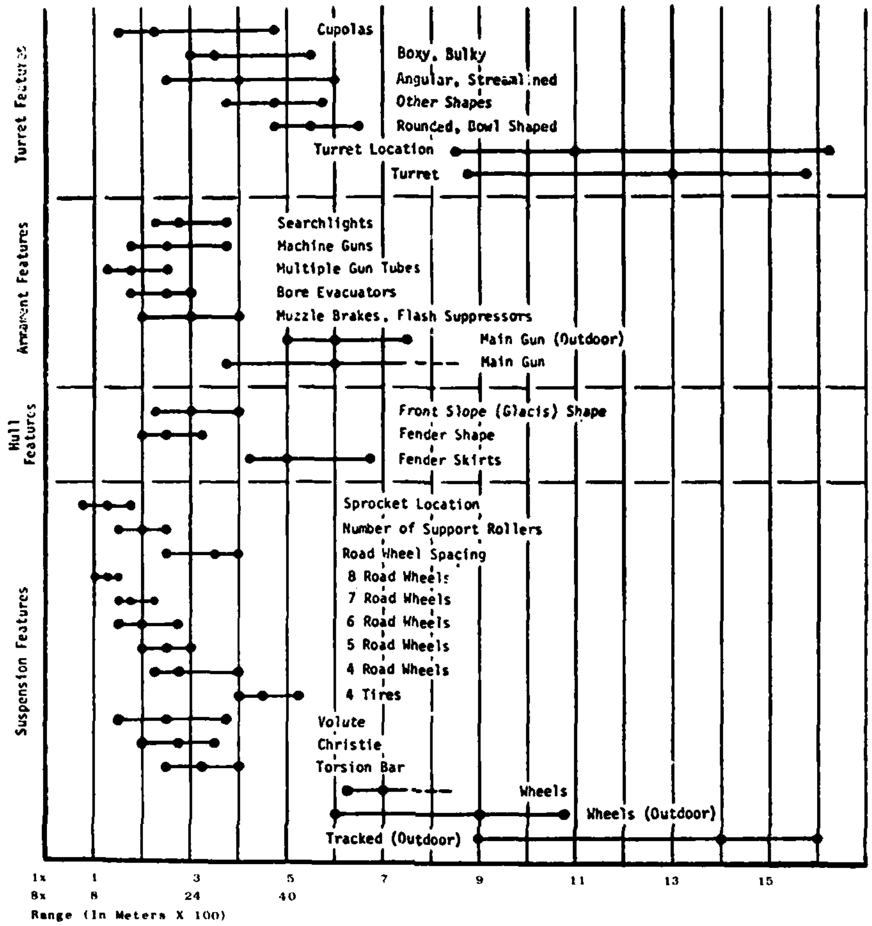


Figure 6. ESTIMATED DETECTION RANGES FOR VEHICLE FEATURES SELECTED BY FOSKETT ET AL. UNDER OVERCAST CONDITIONS, WITH 5 KM VISIBILITY

identification and the impact of observers' criteria may yield information about practical aspects of target identification that have yet to be considered.

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TRAINING TECHNIQUES USING COMPUTER GENERATED IMAGERY (CGI)*

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## ABSTRACT

Aircraft simulators have in the past been designed and used primarily as substitutes for aircraft. CGI provides the flexibility to enhance training in ways not normally possible in an aircraft. This research conceived and demonstrated training approaches to take advantage of this flexibility. Rather than duplicate the real world cockpit environment, this study considers other objectives attainable. This requires a change from thinking of a simulator as an airplane substitute to thinking of it as a training device that can complement 'real world' training from text through actual aircraft. Another change requiring consideration is the expected change in military use of simulators from teaching initial, simple flight skills and procedures, to teaching and maintaining complex combat skills involving interactions among several aircraft and ground systems.

Scene elements were incorporated into a computer generated visual presentation which did not represent "real world" objects, but which were there solely for instructional purposes.

Hopefully these techniques will be used to improve the effectiveness of actual aircraft hours spent in training rather than replace them.

## INTRODUCTION

In the past, aircraft simulators have been designed and used primarily as substitutes for actual aircraft. Computer generated imagery provides the flexibility to enhance training in ways that cannot be done in an aircraft, at least under peacetime regulations. The thrust of this research is to conceive and demonstrate new training approaches to take advantage of this flexibility as a step towards reducing pilot combat attrition and increasing readiness. Two broad categories of techniques are available to us: (1) simulation of tasks *untrainable in aircraft during peacetime but* required during combat, and (2) application of teaching/learning methods unavailable in aircraft. Examples of the first category are surface-to-air missile (SAM) avoidance and air-to-air missile avoidance. This category was not emphasized, since many of these techniques are incorporated in present state-of-the-art visual systems or will be in the near future. The second category is exemplified by techniques such as making visible something that the pilot must visualize but cannot see in the real world (e.g., a radar antenna pattern of an opposing aircraft during air-to-air combat or a diagram of the relative energy state of the aircraft and their flight envelopes, or allowing the student to view an engagement from various viewpoints (his own, ground threats', air threats', overview, etc. (See Figures 1-3).

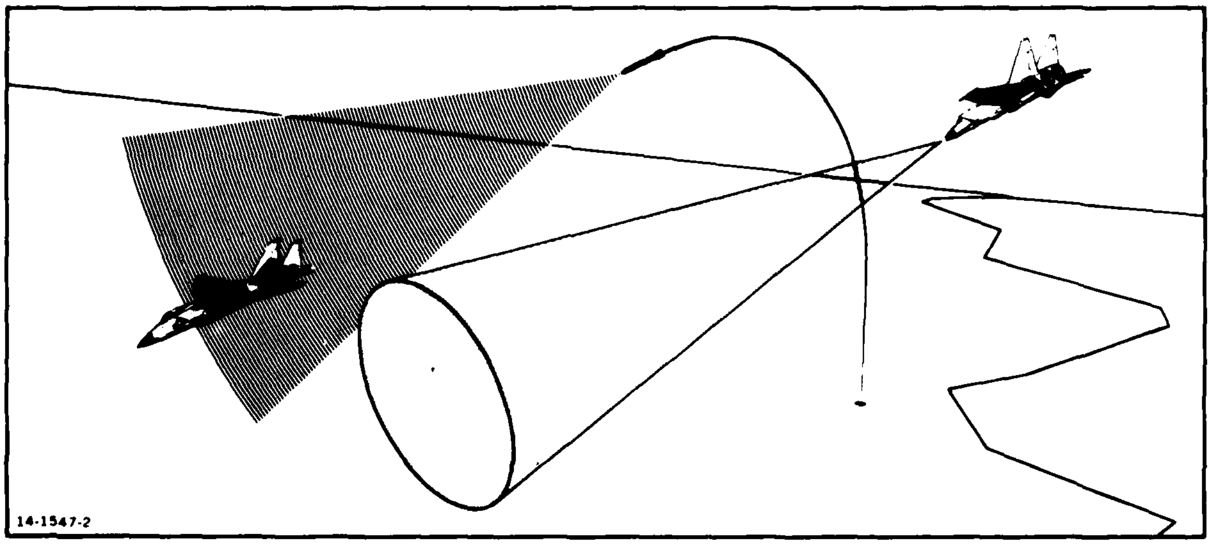


FIGURE 1. VISIBLE THREAT CONE

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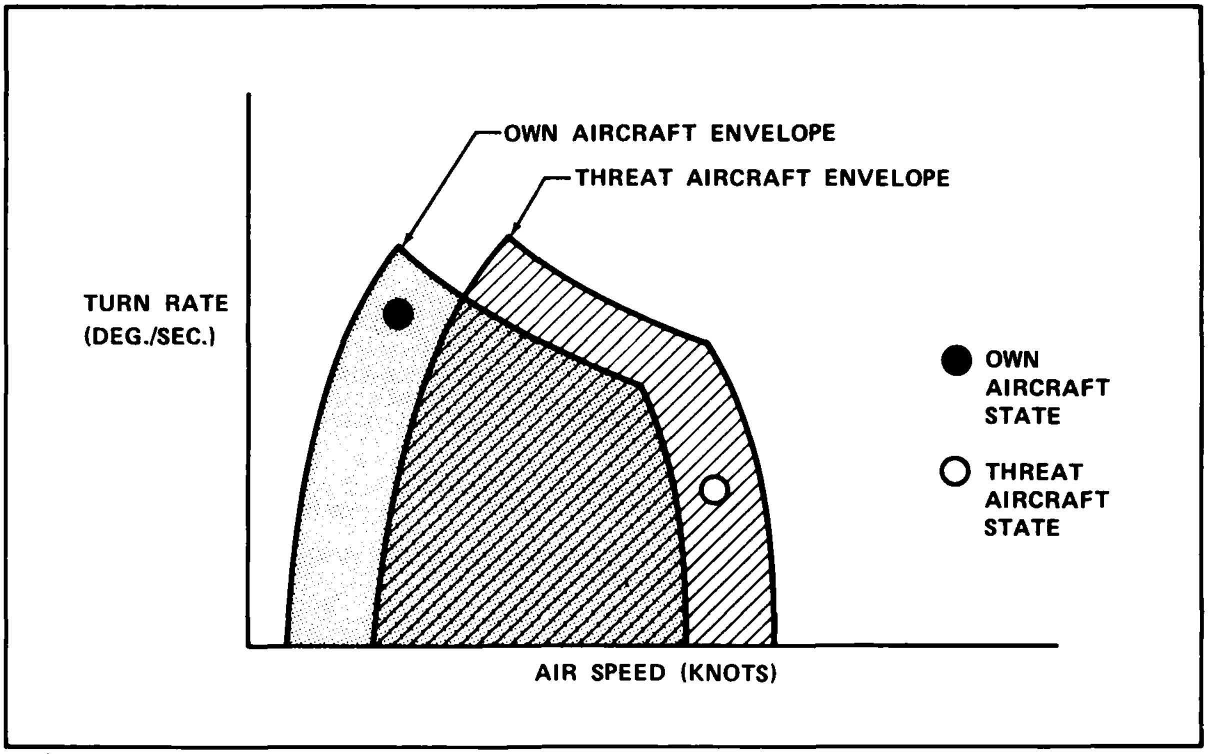


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FIGURE 2. RELATIVE FLIGHT ENVELOPE PERFORMANCE DIAGRAM

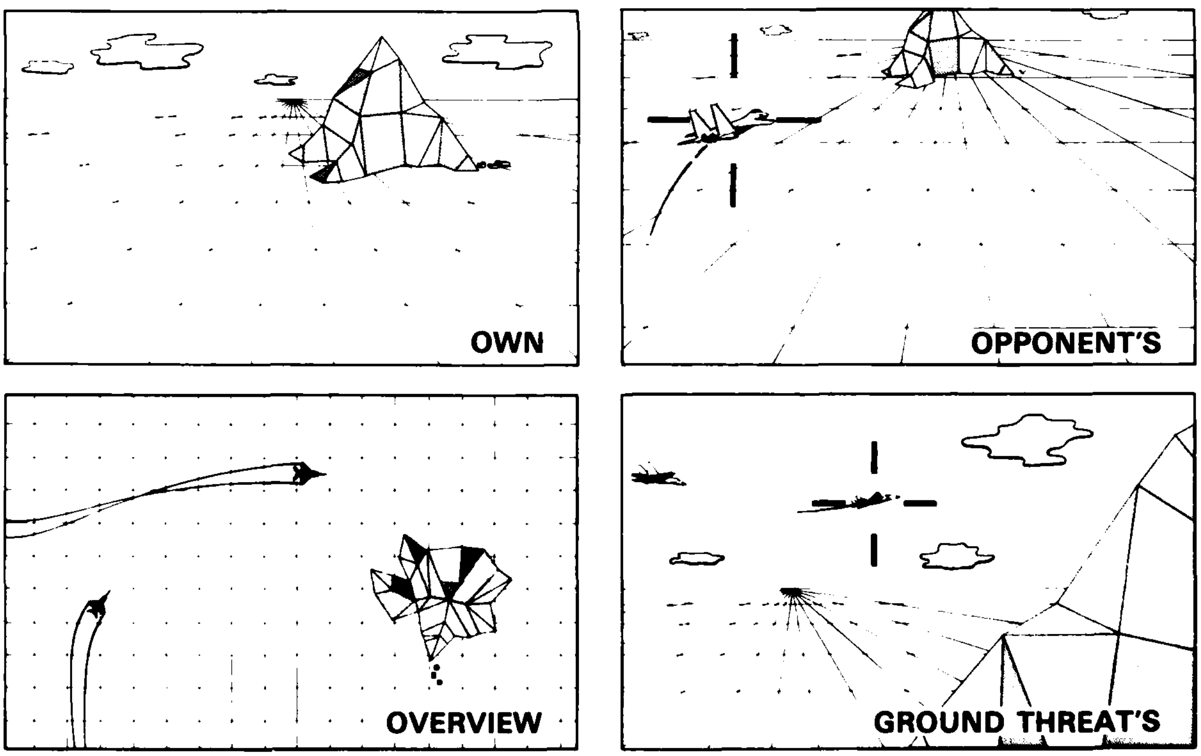



FIGURE 3. SITUATION AWARENESS TRAINING - MULTIPLE VIEWPOINTS

## OBJECTIVE

The objective was to conceive and demonstrate examples, such as described above, of concepts in aircrew training that would take advantage of the *flexibility of computer generated imagery* to provide enabling and instructional features unavailable in the "real world". The emphasis was in complex combat skill training as opposed to simple tasks such as takeoff and landing.

## APPARATUS

Some of the concepts resulting from this effort have been demonstrated on a *VITAL IV computer* generated image (CGI) system, located at McDonnell Douglas Electronics Company. This system consists of a general purpose minicomputer, special purpose high speed computational hardware, and a calligraphic color display with collimating optics as shown in Figure 4. The display is normally mounted outside the window of an aircraft simulator cockpit to display a representation of the "real world" to the pilot. The simulator position and attitude information in the response to the pilot's controls is fed into the visual system which updates the scene correspondingly thirty times per second. Typical scenes are shown in Figure 5. The scenes are made according to customer desires and have in the past been made specifically to simulate the real world flight environment including special effects such as variable weather conditions, surface-to-air missiles, air-to-air missiles, anti-aircraft artillery, tracer bullets, and so forth.

All of these scenes are made up using two basic elements, flat convex polygonal shapes and strings of light points. There are no restrictions however on how one can use these basic scene elements. In particular, they need not be used to make scenes to look like the "real world." It is the objective of this project to explore these other uses to which the basic scene elements (common to many computer generated image systems) may be put.

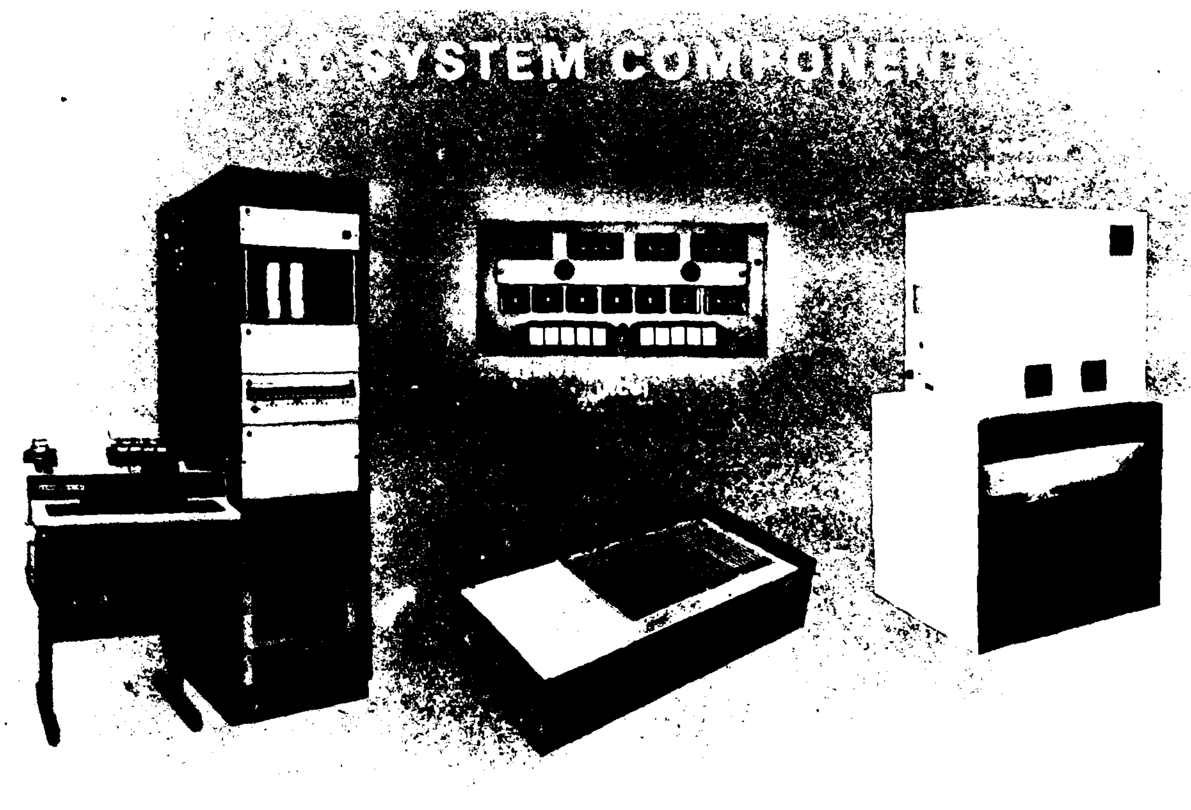



FIGURE 4. VITAL III SYSTEM COMPONENTS

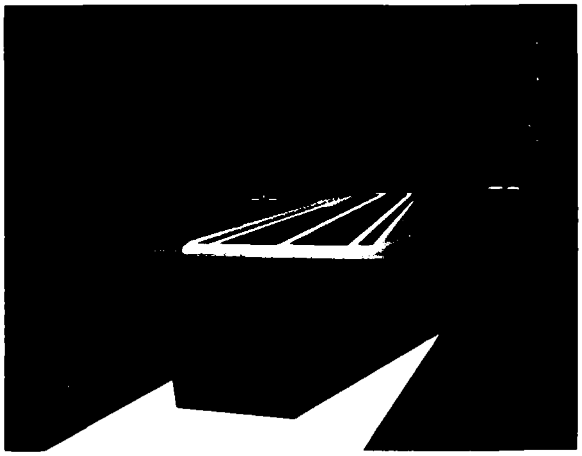
## IDEA GENERATION PROCESS AND RESULTS

To provide a framework for the idea generation process a list of key issues to be trained was drawn up (Table 1).

Simultaneous with the generation of specific training techniques a list of generic techniques was created to avoid getting into a rut of essentially similar approaches. In the next year's work the idea generation process will continue but will have the added benefit of feedback from preliminary trials.

## GENERIC TECHNIQUES

A list of generic training techniques is given in Table 2. Each will be discussed in the paragraphs that follow. These are not all claimed to be new, nor is the list comprehensive.

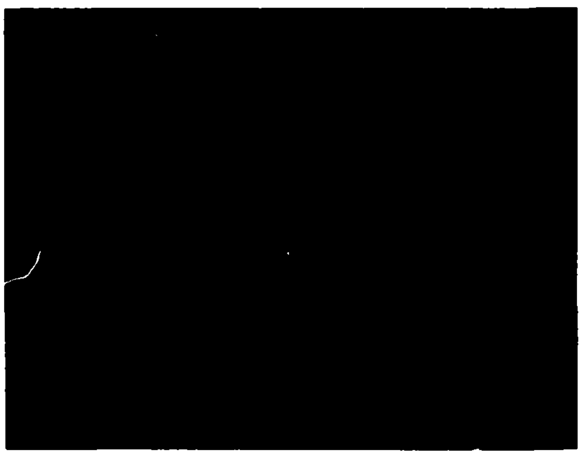


AIRCRAFT CARRIER WITH
SEA SURFACE AND WAKE

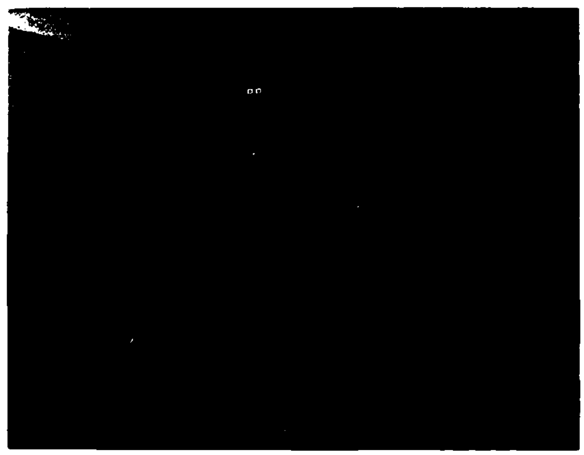
NEW YORK – LAGUARDIA (TWILIGHT)

MINNEAPOLIS – ST. PAUL
INTERNATIONAL (TWILIGHT)

KC-135 TANKER



MINNEAPOLIS – ST. PAUL
INTERNATIONAL (NIGHT)



GROUND TARGETS

FIGURE 5. TYPICAL STANDARD VITAL IV IMAGERY

TABLE 1. KEY ISSUES TO BE TRAINED

A. Factors Affecting Probability of Kill ($P_K$)

1. Energy Management

   a. own
   b. threat energy state

2. Offensive Weapons Systems

   a. switchology
   b. knowledge of best system selection

3. Assessment of Threat (Current)

   a. status assessment
   b. knowledge of what to do about it.

B. Factors affecting Probability of Survival ($P_S$)

1. Energy Management

   a. own
   b. threat (know energy state of threat)

2. Defensive Systems Management

   a. display threats
   b. respond to threats

3. Assessment of Threats

   a. status/number
   b. knowledge of what to do about it.

C. Maximizing $P_K \times P_S$

TABLE 2. GENERIC TEACHING AID SUMMARY

1. Make visible something the pilot normally cannot see but tries to model or *visualize in his* mind.
2. Perspective changes. Allow pilot to select various viewpoints in his out of the cockpit scene (e.g., overview, threat's view, etc.).
3. Demonstration and/or exaggeration.
4. Awareness stimulators.
5. Pointers for instructor and/or student.
6. Sense exercise.
7. Dynamic student control of scene and cues.
8. Analogies.
9. Cue indicators.
10. Cue supplementation or augmentation.
11. Adaptive aids.
12. Scoring and immediate error feedback.
13. Feed forward predictors.
14. Time compression or expansion.
15. Time quantization or task segmentation.
16. Discrete indicators (situation recognition/response).
17. Abstraction

1. Make "visible" something the pilot normally cannot see, but tries to model in his mind - For example, let's say a pilot knows that another aircraft will have to get him within a 10-degree cone and within a six-mile range to lock on some particular kind of missile. This "cone of danger" emanating from the nose of the other aircraft needs *to be visualized by the pilot, so that he may avoid* it. This visualization in three dimensions under a wide variety of circumstances could be taught by simply showing the cone emanating from the other aircraft in a computer generated image visual system. As the pilot flies against this target, he can learn to internalize the image of that lethal cone for use in the 'real world', where the cone is invisible. Obviously, there are many other examples of situations where this technique of making a cue available in the simulator that is hidden in the real world could be expected to be useful for training.

2. Perspective Changes - Advanced pilots generally do not view their actions only from their own viewpoint, but abstract the situation to an overview or "God's eye view". Some simulator instructor stations show this viewpoint to the instructor or to the student after an engagement. More immediate feedback to facilitate this perspective abstraction could be given by allowing the student to change the viewpoint being displayed while still in the cockpit. Other viewpoints could also be helpful, such as how he looks to a ground threat or to his opponent. This type of technique might aid in the development of situation awareness.

3. Demonstration/Exaggeration - If a subtle cue must be detected by the pilot, it can be helpful to exaggerate the cue first, so that the pilot has a good awareness of what he is looking for. For example, a pilot has an altitude below which he is so involved in avoiding ground impact that he can not perform other tasks. That altitude is his "comfort level". If it is desired to demonstrate to the pilot that his comfort level depends on his speed, a simulated course may be flown at Mach 3 and then at 30 knots before allowing him to learn his comfort level for more normal speeds.

4. Awareness Stimulators - There is a dangerous tendency for a pilot while performing a difficult task, such as air-to-ground or air-to-air attack, to focus on that task to the exclusion of perception of other events around him. To maintain the pilot's awareness, other objects or events could be presented in the scene, such as other aircraft, and the pilot's ability to monitor them during his task could be included in his score for the task.

5. Pointers for Instructor and/or Student - It has long been known that a simple pointer is useful in communication about visual displays, yet no aircraft simulator has such a pointer available for use in the out-of-the window scene. There are at least three ways such a pointer could be used once positioned by either the instructor or student. When released it could remain stationary in ground coordinates (three dimensional), or in display screen coordinates (two-dimensional), or it could remain a fixed number of degrees below the horizon. This last method of operation would be applicable to designating a particular dive angle or glide slope.

6. Sense Exercise - A computer generated visual system can readily be used to give a student practice in certain types of fine perceptual tasks with feedback such as immediate knowledge of results. There are many useful examples of this technique; one could practice closure rate judgements, target aspect from motion judgements, landing flow pattern discrimination, low contrast target detection, scan patterns, and so on.

7. Dynamic Observer Control of Scene and Cues - For example, if it is desired to teach a student to judge target aspect, he could be given control of the target as if it were a remotely piloted vehicle. If the aspect were uncertain, he could test it by seeing how it responds to his control inputs.

8. Analogies - It is often useful to show similarities between a task to be learned and a more familiar task. It may even be useful to teach a simple task for later use in analogy to a more complex task.[1]

9. Cue Indicators - There are many subtle cues in flying. These may be indicated to the student in a variety of ways such as, use of a pointer, exaggeration, elimination of other extraneous cues, and so forth.

10. Cue Supplements or Cue Augmentation - Subtle cues may initially be supplemented with more obvious ones, to lead quickly to correct performance and then weaned away as the student's proficiency increases. This would be particularly adapted to the case where the pilot is learning two different tasks simultaneously, while one is dependent upon the other. For example, in landing, the two tasks are: controlling the airplane, and perceiving the flight path. One cannot control the airplane without perceiving the flight path and one cannot test one's flight path perception before getting the airplane under control. This contradiction can be avoided by supplementing the normally subtle flight path perceptual cues until control is learned and then teaching the perceptual task of detecting glideslope deviations from subtle cues.[2]

11. Adaptive Aids - This is a broad category which must be carefully used to avoid student dependence on the aid, but can be extremely effective in quickly making the student capable of performing correctly. The visible adaptive glide slope of Gaven Lintern[2] of the University of Illinois is an example.

12. Scoring/Error Feedback - This is not a new technique, but it certainly could be used in new ways. Computer generated image out-of-the-cockpit displays provide the opportunity for quicker feedback, which is known to produce quicker learning. An example of this technique would be to superimpose scoring data on the pilot's outside scene during a training flight in the simulator. For instance, the pilot's probability of survival could be displayed in a corner of the scene as a bar graph ranging from zero to one and if the probability gets too low, the computer could display a brief explanation of what he has done wrong immediately, while he is still in the cockpit, instead of waiting until later. For bombing practice, miss distances and aircraft parameters at time of release could be shown after each bombing pass.

13. Feed Forward/Predictors - An example here would be during air-to-air combat. When a pilot is on the offensive, he could be shown where his present course and closure rate would cause him to intercept the target's flight plane.

14. Time Compression/Expansion - Sometimes events occur too quickly for the novice to appreciate them individually and to think through the ramifications. Conversely, the more experienced student may need to "over-learn" one task, to be able to perform other tasks simultaneously. One could slow the system down for the former and speed it up for the latter. This technique might also be used to simulate the situation when one's internal clock is running faster than normal.

15. Quantization of Time - A task can be broken into discrete steps such as in the task taxonomy of Robert Meyer[3]. These may be learned singly in whatever order is best suited to learning. Examples would be the backward chaining technique of Hughes[4], a slide presentation, or flash cards.

16. Discrete Indicators - A simple discrete indicator can be used to teach the student to recognize and respond to a particular situation. In teaching low level flight, if it is desired to stay below 250 feet, a simple tone or indicator could be given when that limit is reached or exceeded.

17. Abstraction - In air-to-air combat it is useful to view what is happening and develop tactics from the point of view of where each aircraft is in a relative performance diagram, such as a plot of air speed versus acceleration (g - forces). This is an example of abstracting events. Another example might be to teach certain perceptual tasks in a scene not at all resembling the "real world" and then transfer the skill to the real world or realistic simulation situation.

## SPECIFIC EXAMPLES

Specific examples of training techniques possible using computer generated imagery follow. They do not have a one-to-one relationship with the generic technique list. Most of the specific examples incorporate several of the generic techniques at once. Also, each generic technique is represented in several specific examples to varying degrees.

1. *For the task of training air combat maneuvering defensive tactics, it may be useful to enhance the defender's awareness of the attacker's "lethal cone". The "lethal cone" might be the attacking aircraft's antenna pattern within which he could lock on and launch an air-to-air missile. This pattern could be represented by a cone of appropriate range and angle visibly emanating from the attacking aircraft. This could be modeled red on the inside and green on the outside so that the defender would immediately know when he is in this danger zone. The main objectives here would be to teach the pilot how this normally invisible cone looks in three dimensions from the various positions attained during an engagement, and to allow him to develop techniques for avoiding it. One would have to take care with such a technique not to overuse such an added cue to the point of dependency. (See Figure 1.)*

2. *In air-to-air gunnery using tracer bullets, it is difficult to judge where the bullet passed closest to the target, and hence the miss distance. A simple way to aid this judgement would be to indicate to the pilot where this point is. This could be accomplished in a number of ways. Perhaps the simplest is to change the brightness of the tracers once they have passed the target range. (See Figure 6.)*

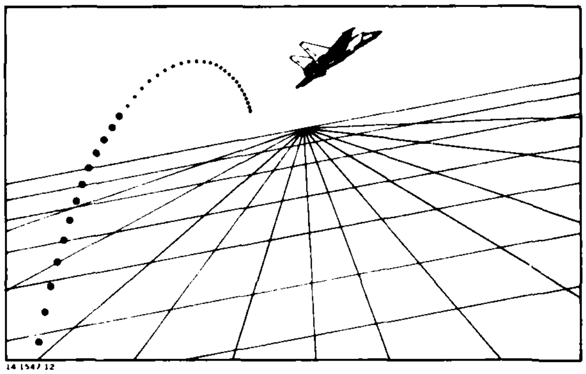


FIGURE 6. TRACER RANGE JUDGEMENT SUPPLEMENT

3. There is a large number of situations in which it is useful for the pilot to know his or another aircraft's flight path either during or immediately after a maneuver. This can apply both to air-to-air and air-to-ground combat. In some cases this type of information is already being used in training. On the Air Combat Maneuvering Range (ACMR) several pilots can fly instrumented real aircraft in an engagement and later review on ground displays what happened as seen by an instructor operator from the ground during the engagement. This is very useful, but unfortunately it requires delayed feedback of several hours. Some simulators present this information to the instructor/operator, but it is again unavailable to the pilot without delay. There is no reason at all why this information cannot be presented to the pilot in the same out-of-the-window display he uses in the simulator for training. This can reduce feedback delay to zero or negligible times whichever yields the best training for a given situation. A simple way to think of implementing this is to have the aircraft drop a trail of zero muzzle velocity tracer bullets as it flys along. This visible trail could be used in a wide variety of ways. It could be viewed during an air-to-air engagement or immediately afterward. (See Figure 7.)

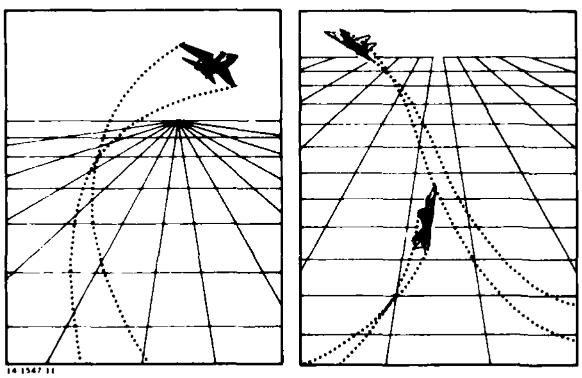


FIGURE 7. VISIBLE PATH, CONTRAILS, OR RIBBONS

This technique can usefully be joined with the one described in the next example (number 4).

4. It is of paramount importance for a combat pilot to develop what is referred to as "situation awareness." This involves a constant appraisal by the pilot of the factors in Table 1. He must be continuously aware of what is going on around him, where he is, and what to do about it. This is not easy to do while performing difficult tasks. Advanced pilots frequently comment that they do not always think of their situation from their own point of view. Rather they may view the situation from an overview or from some abstract viewpoint (discussed further in example number 17). As an aid to teaching this situation awareness, one could allow the pilot to literally see what is happening from several different viewpoints at his selection either during or immediately after a simulated engagement. Useful viewpoints would include, in addition to his own: an overview or "God's eye view", an opposing aircraft's view, and a ground threat's view. There are even situations where a viewpoint attached to but outside of his own aircraft would prove of utility. (See Figure 3.)

5. A simple method for an instructor to enter and store a flight path into the visual database to be either viewed and/or followed by the student would be to have him fly the route or maneuver while leaving the visible path as described in example number 3. The instructor could, for instance, lay a trail showing an ideal air-to-ground delivery or air-to-air maneuver. The student could then attempt to retrace this path while also dropping "bread crumbs" to mark his path. The two paths could then immediately be visually compared while the instructor provides comments. Alternatively, the instructor's path could be kept invisible until the student's maneuver also was completed and then the paths could be compared. (See Figure 8.)

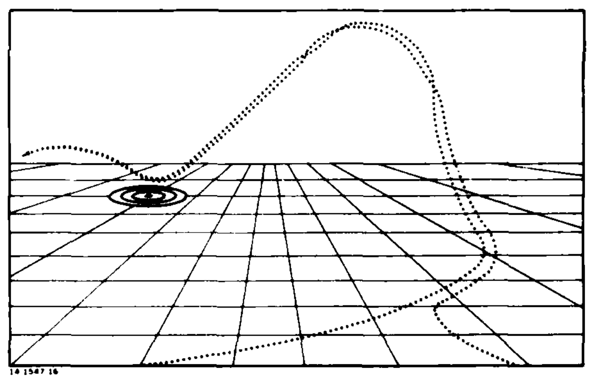


FIGURE 8. VISIBLE INSTRUCTOR DEMONSTRATION PATH

6. Situation awareness and target aircraft motion judgement training could be addressed by entering a large number of moving airborne objects in the scene. For this purpose they need not be models of aircraft but could be any identifiable object. While performing some task, for example ordnance delivery, the pilot would have to monitor continually the position, velocity, and direction of each of the moving objects. These objects are illustrated below as flying numbers. The pilot could be tasked with calling out which number is closest or approaching the fastest and so forth. If the computer monitored the pilot's head and/or eye position, it could even perversely bring objects into view from wherever the student was <u>not</u> looking. This would force him to learn effective scan patterns. (See Figure 9.)

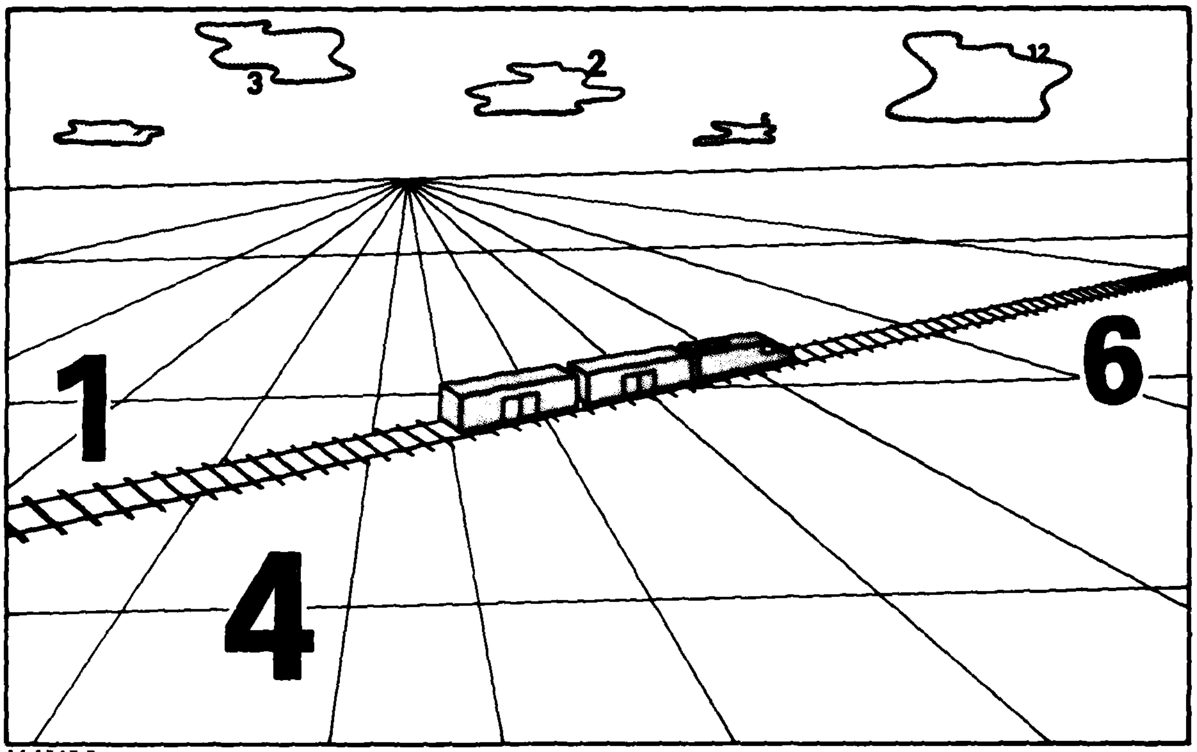



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FIGURE 9. SITUATION AWARENESS TRAINING

7. A cursor has long been used as a valuable tool in computer-aided design applications. It would be equally valuable as part of the computer-generated scene in aircraft simulation visual systems. In that application a number of useful modes of operation can be envisioned that would allow instructor and student to more easily communicate about the visual scene. One mode would be as presently used in other applications, that is a two-dimensional cursor in display window coordinates. Another would be a cursor that moved in three-dimensional ground coordinates. A particularly unusual mode of use in flying training would be a cursor that moved in coordinates relative to the horizon. For example, the cursor in this last mode could be set to 30 degrees below the horizon and would thus help the student learn to establish a 30 degree dive bombing angle to a particular target. A similar cursor set at 3 degrees below the horizon would continuously point to the landing spot that would be impacted if the plane held a 3 degree glideslope. Simply setting the cursor to various known degree settings below the horizon would aid the student in learning some important visual judgements.

8. Visual exercise may improve judgement of air target or other motion cues. The student could spend time looking at displays showing moving objects (using monocular and/or binocular cues). Such displays are particularly amenable to computer generation. They need not necessarily look like real world objects. In fact the optimization of what display to show and the feedback of results schedule would be an intriguing study in itself. It might turn out that abstract displays of some sort optimally exercise these visual senses. Perhaps sense exercise is separable from teaching judgements using that sense. The first might address lowering of perceptual thresholds, while the other would address quantitative suprathreshold judgements. (See Figure 14.)

9. In learning to judge distant target aspect angle and motion it may be very useful to let the student practice flying simulated remotely piloted vehicles (RPV's). This task requires knowledge of aspect and motion to succeed and could aid in learning aspect since the aspect can be determined from reactions of the RPV to the pilot's controls. This task might also help develop the ability to visualize a situation from another viewpoint as discussed in example 4. (See Figure 10.)

10. When a pilot is performing a task that is very demanding his attention tends to concentrate on that task. His attention to peripheral cues is reduced. There are two ways to attack this problem. One mentioned in example 6 is to attempt to teach him to overcome this tendency to overconcentrate his attention. The other, which may complement the first, is to help him learn to at least get the most from the information available in the narrow area of concentration. Thus one could practice flying with minimal cues such as available in the immediate target area. (See Figures 11 and 12.)

11. While flying, a pilot generates and maintains an internal model of where he is with respect to other objects such as the ground, other vehicles, or a particular target. He continually updates this model from all available sources of information using all of his senses. The ability to accurately update this model from limited or con

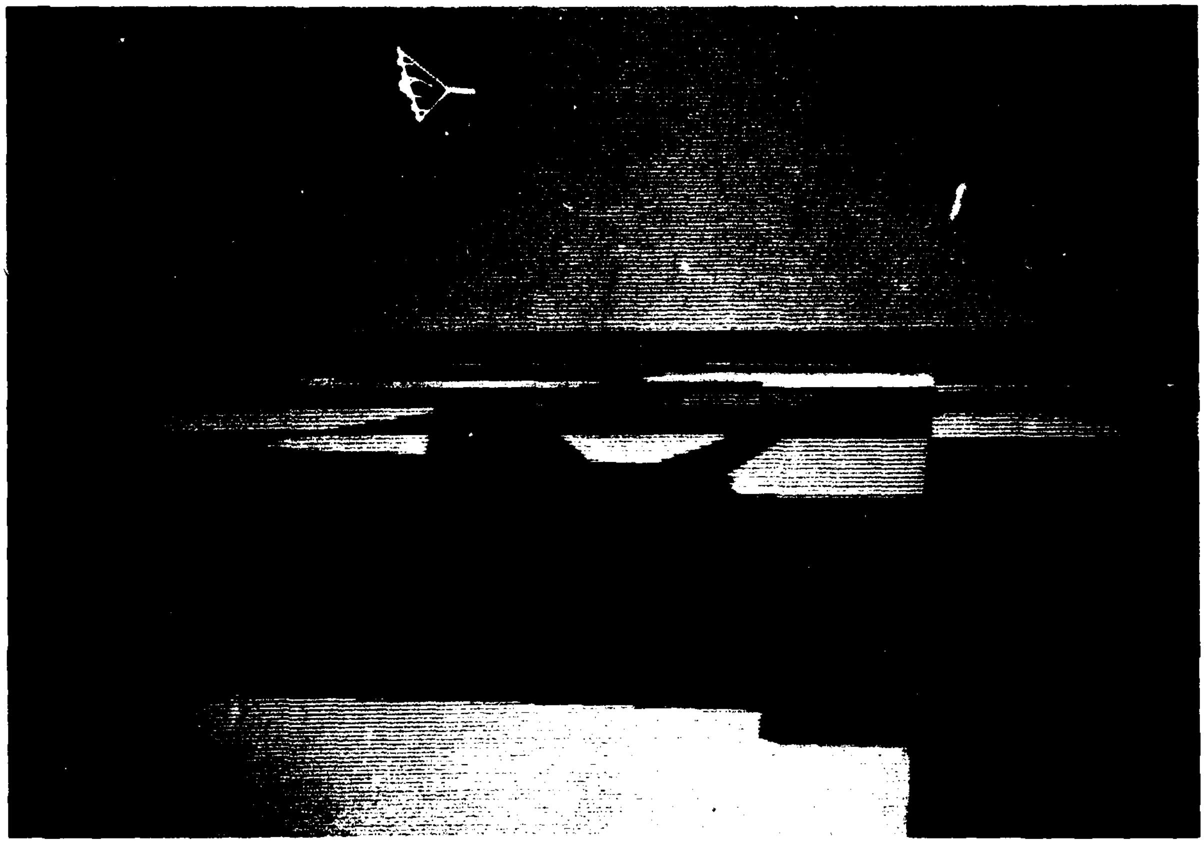

FIGURE 10. PRACTICING ASPECT AND MOTION JUDGEMENT BY FLYING SIMULATED REMOTELY PILOTED VEHICLES

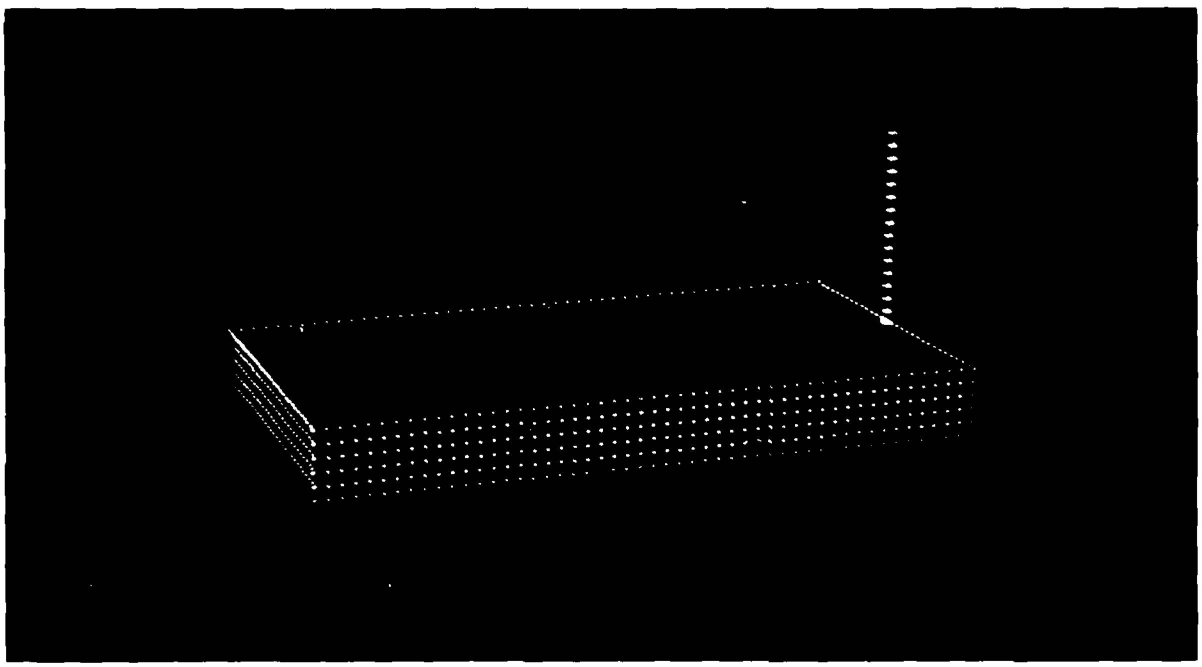

FIGURE 11. MINIMAL CUES - LEARNING TO POSITION ONESELF WITH RESPECT TO A SIMPLE BALL OR CUBE WITH NO OTHER CUES AND/OR WITH A HORIZON

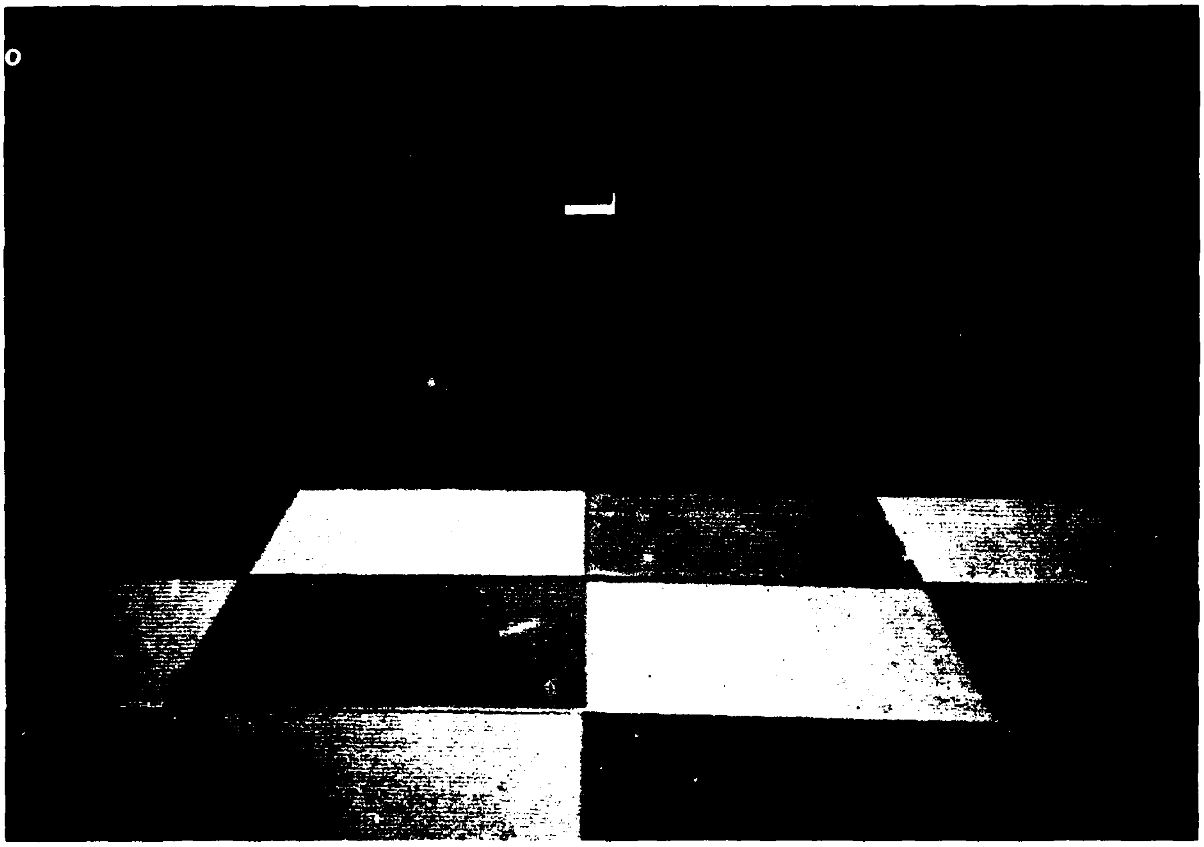

FIGURE 12. TARGET AREA ONLY CUES SCENE

flicting information is useful. An example would be the situation in which a pilot is attempting to attack a ground target by dive bombing. During the initial attack phase the target might appear off to one side. He could fly along till the target approaches 90° off to one side then roll the aircraft to turn towards the target. Prior to the roll maneuver he would generally look sometimes at the target to update his internal model of its location with respect to him, and at other times in front of his aircraft to check his flight direction. Flying an aircraft in one direction while looking for a prolonged period in another direction could cause disorientation. Hence the pilot is tempted to move his eyes and, hopefully less so, his head back and forth between these two data sources to maintain the accuracy of his internal situational model. It might be worthwhile to give the pilot practice flying the aircraft in one direction while his field of view is limited to another direction such as at the target. He might then learn to update his internal model accurately from different information than he usually uses, requiring reduced head movement for this task and allowing more concentration on the target. A caveat is that he still would have to look in other directions to maintain awareness of other vehicles in the area.

12. The ideal position, size, and shape of a target ("sight picture") for a particular type of air-to-ground attack could be shown for comparison to how it looks during the student's approach. (See Figure 13.)

13. The angle of attack (the angle at which the airplane wing meets the air[5].) of an airplane in flight is of paramount importance to flying. Yet, it is not readily apparent in a real airplane unless indicated by an instrument. A pilot must learn to appreciate angle of attack, but in the real world other cues such as those to pitch angle are much more prominent and at first divert his attention from this important concept. In the computer generated simulation one can remove the extraneous cues and initially supplement the cues to angle of attack. The student could fly in a scene with no ground or horizon references at all to avoid confusion and the air could be made visible by filling it with points so that angle of attack could easily be judged. Thus the student would first learn to fly with respect to the air, not the ground. One could also, in this environment, position the pilot outside the plane (either fixed with the plane or fixed with the air) to make visualization and understanding of relative wind easier. Then, with this firm foundation, the ground reference cues such as pitch angle could be brought in with less confusion. He would for instance become more readily aware that the stick is not the up lever. The scene for this training situation might have the points representing the air randomly distributed in a volume to preclude any pitch cues. A similar scene, but with the points regularly distributed, could be used to teach perspective judgements and motion judgements frequently used in flying such as location of the "aim point", the point toward which the aircraft is headed. Another use

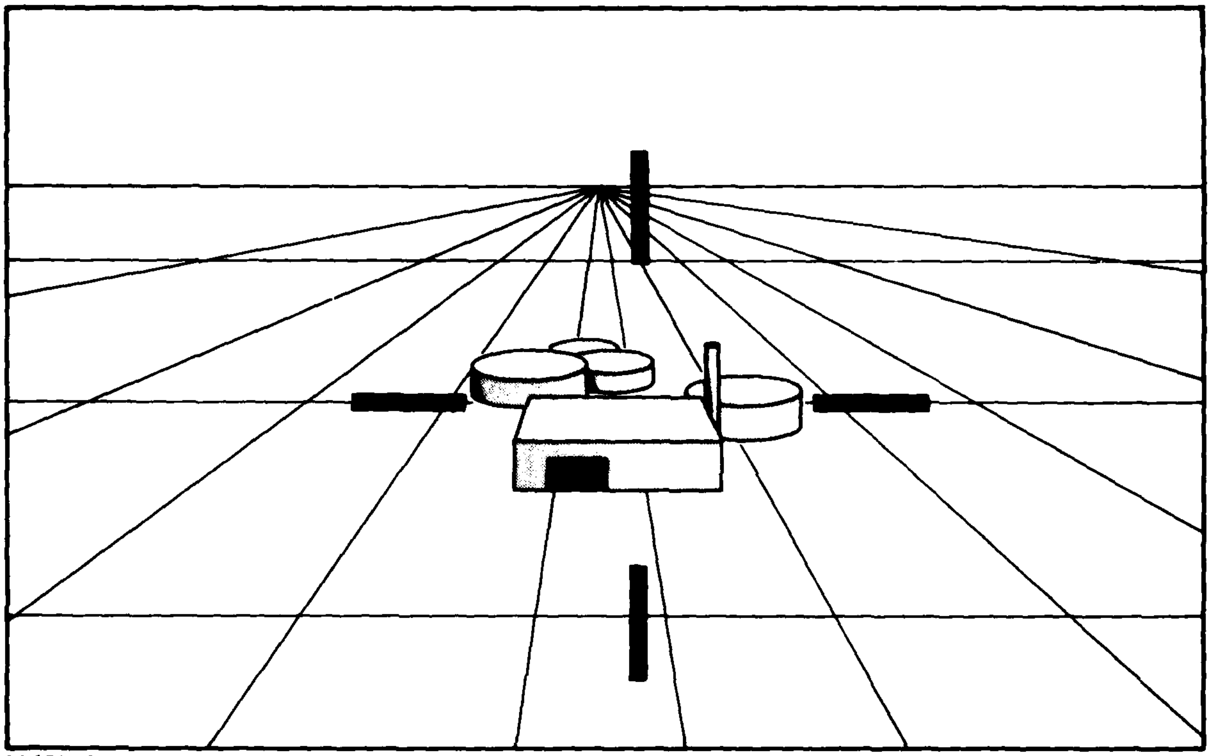

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FIGURE 13. IDEAL SIGHT-PICTURE DISPLAY FOR COMPARISON DURING AIR-TO-GROUND ATTACK TRAINING

for such scenes would be to exercise visual perception of motion. (See Figure 14.)

14. To aid in learning the proper sight picture and how to make corrections during dive bombing one could show a cone emanating from the target at the proper dive angle so that the pilot knows when he is at the proper dive angle or how far off he is.

15. Although it would be difficult to compute, it could be useful to provide the student pilot with a cue to his fluctuating probability of survival ($P_s$), probability of killing a target ($P_k$) or a combination of the two such as $P_s \times P_k$. This could be done by showing an object in a corner of the display which would change as $P_k \times P_s$, $P_s$, or $P_k$ change. This would be particularly useful in teaching tradeoffs between offensive and defensive tactics in crowded dogfights.

Another way to implement this might be to have the display grow more red as the probability of survival is reduced. (See Figure 15.)

16. Showing the student pilot a predicted path for himself and his opponent including an indication of relative speed at intercept to help him learn to judge when he would overshoot, when to bleef off energy, and when to discontinue bleeding off energy could help give the student a feel for optimum solutions in various basic air combat maneuvering (ACM) situations and help him learn energy management.

17. In air combat it would be very useful for the student to learn to detect, take advantage of, and affect a threat aircraft's "g" state, energy state, and where the two aircraft are in their relative performance envelopes. This type of information could be presented in the training simulator even though it might clog his already overloaded sensory channels to put it in the actual aircraft in combat. An ideal example of this approach is given in Moroney, et al[6]. (See Figure 2.)

## DEMONSTRATIONS

Several of the specific techniques have been implemented on the MDEC VITAL IV system. These are:

1. - Visible lethal cone
3. - Visible aircraft paths in sky (wing tip ribbons).
4. - Multiple viewpoints.
7. - Cursor
10. - A minimal target cues scene in which most of the scene elements (horizon, target, ground grid) can be independently turned on or off.
13. - A scene having no ground or horizon references composed of a solid cube of light points.

A small number of people have flown these scenes and found them exciting and challenging. It will take some practice utilizing these scenes to learn what effects they have and how to make the most of them.

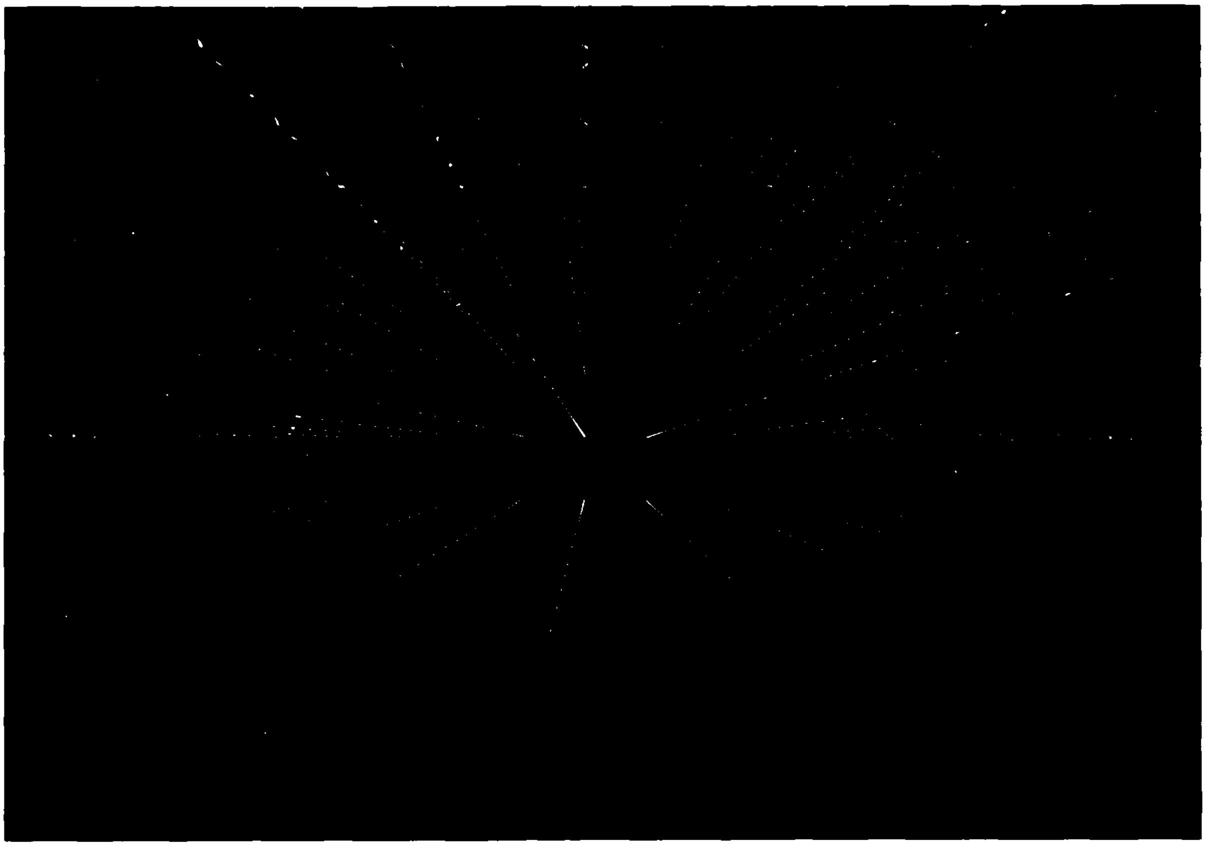

FIGURE 14. VISIBLE AIR FOR ANGLE OF ATTACK, PERSPECTIVE JUDGEMENT TRAINING, OR SENSE EXERCISE

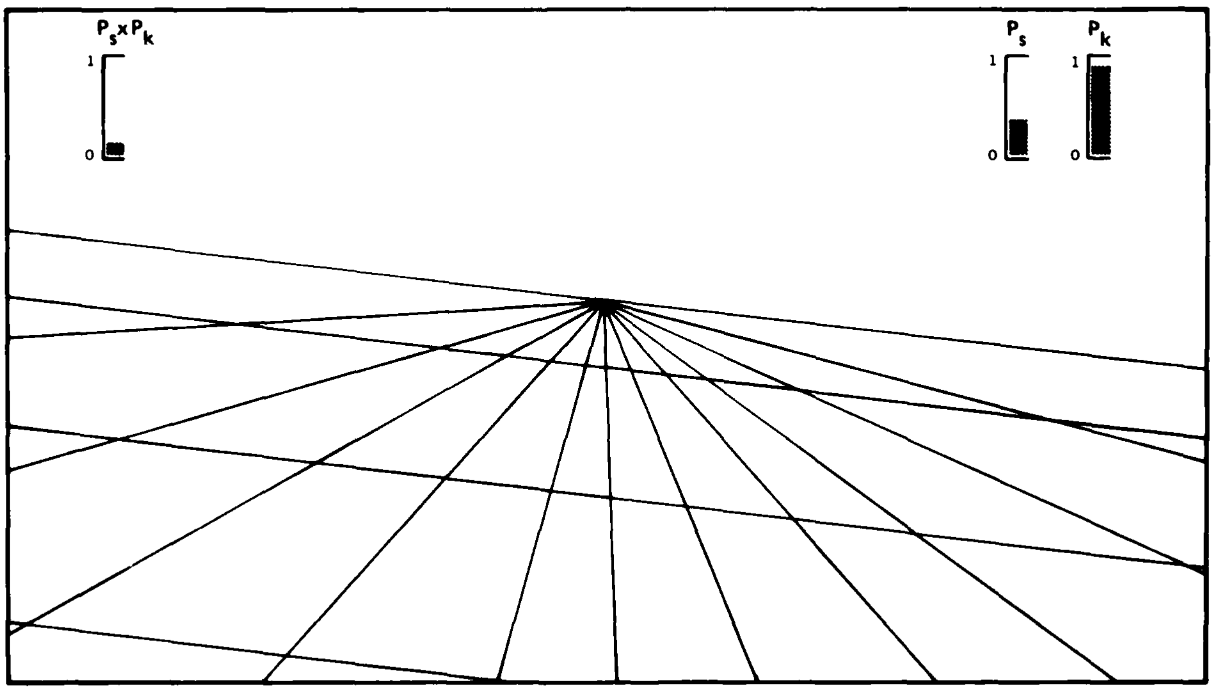


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FIGURE 15. PROBABILITY OF SURVIVAL AND KILL INDICATORS

## CONCLUSIONS & DIRECTIONS FOR FUTURE WORK

This report represents a mere tip of the iceberg compared to the vast array of training techniques that are made possible by computer generated visual simulation. The objective of this study was to generate and demonstrate concepts in aircrew training methods that take advantage of the flexibility of computer generated imagery. While in the past the main objective of simulation was to duplicate the real world cockpit environment, we are now in a position to consider other objectives that will be attainable with training devices. This requires a change in orientation from thinking of a simulator as an airplane substitute, to thinking of it as a training device that can complement "real world" training as part of a total training system which cohesively runs the gamut from text through actual aircraft. Another change requiring new thinking is the expected change in military use of simulators from teaching only initial, simple flight skills and procedures to teaching and maintaining of complex combat skills involving interactions among several aircraft and ground systems.

The study attempted to take a step in this direction by creating examples of ways a computer generated visual system could be used within this context. Scene elements were incorporated into the visual presentation which did not represent "real world" objects, but which were there solely for instructional purposes.

Lists of generic and specific training techniques were generated, some of which are presented here. Selected examples were implemented on a VITAL system at McDonnell Douglas Electronics Company. A list of key issues to be trained was drawn up to provide a framework for concept generation. Upon examination of the above mentioned lists, it was noticed that most of the listed techniques are intended to address the teaching of "recognitional" type tasks as defined by Klein[1]. They tend to make use of the learning theory principle of immediate feedback of results and are amenable to inclusion within holistic and/or adaptive training schemes as well as more standard techniques.

The next stage of this work will involve exploratory testing of some of tne techniques discussed in this report. A portion of this work will be performed at MDEC using relatively inexperienced pilots drawn from the flight student population at Parks College of St. Louis University. The class of 289 students should provide an ample subject pool. The remainder of the exploratory testing will be performed on a VITAL equipped flight simulator being used by the Air National Guard which will provide a high experience level subject population. Feedback from these activities will refine the present concepts and perhaps stimulate new ones. The results will serve several purposes. Feedback will be provided from operational users into the idea generation process to more directly and effectively serve their needs. The study will aid in the selection of effective techniques for further more formal testing by others which, in turn, would provide the type of hard data required to support incorporation of these techniques into operational training programs.

The inspiration, direction, moral, and financial support of the Air Force Office of Scientific Research, and in particular Major Jack Thorpe and Dr. Genevieve Haddad, contract monitors, is gratefully acknowledged.

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# DIGITAL VISUAL SPECIAL EFFECTS

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## ABSTRACT

LINK has developed techniques that significantly improve the usefulness and appearance of visual scenes without expending an undue amount of visual system capability. Much of this work used face or object substitution, real-time data base manipulation, and further frame and field logic to produce extremely realistic sea scenes including sea state, bow and stern wakes, and land scenes such as smoke, steam, rotor blades, weapons effects, etc.

These techniques will be discussed and a short movie illustrating some of the most dramatic effects will be shown.

## INTRODUCTION

First-time observers of digital visual systems often react somewhat negatively to the scene. No matter how many edges are employed, the scene does not contain nearly the amount of detail that is apparent in home TV. Even the most detailed scenes appear sterile and lifeless. To sum up the comments of the observers, the scenes are "cartoonish".

Even at the most complex detail level, a computer generated scene is only an abstraction of the real world. No amount of hardware, texture, faster processors, etc. will alter this fact. That such scenes are abstract, however, should not produce such strong negative reactions, for the eyes and the mind abstract constantly from the real world, selecting information from a shifting complex of images.

Interestingly, it has been universally observed that simulated scenes become much more realistic when a pilot is task-loaded. At our plant, where an interactive air-to-air helicopter combat system is in operation, all of the military personnel who have flown in combat have remarked that there is no scintillation, data base error, truncation, nor any cartoonish quality to the display as soon as the "enemy" fires a rocket past their windscreen. It would appear, then, that as soon as some action or movement engages the viewer, the problem of abstraction is very greatly reduced. With this in mind, we decided to substitute movement for detail as a way to make simulated scenes more realistic. By adding dynamic background objects we have made the scenes kinetic instead of static, giving "life" to the displays. The movement keeps the eyes and mind busy and does not permit them to concentrate on the lack of detail; the shifting quality of the scene allows the brain to perform, apparently, in a more normal way, selecting focus objects from a variety of images. We feel that we have made a significant advance in the "state of the art" and that what we have been able to accomplish marks only the beginning stages of a process which may aid computer simulation technology enormously.

Only a few of the many special effects that have been developed will be discussed in this paper. These are dynamic sea state, realistic bow and stern wake, ship motion, and semi-opaque images (suspension bridge and rotor blades).

We will show in detail how each effect was generated and present a movie with each segment, shown first in slow motion and then in real-time. All of these scenes were taken directly from the LINK research simulator in the Sunnyvale Laboratory.

## SEA STATE

### Static 3D Waves

The 3D waves were modeled as small mounds. These "mounds" were scaled smaller than hills and coded blue rather than green. When the results of the first model were displayed, it became apparent that the problem with 3D waves is identical to the problem with the appearance of low hills in nap-of-the-earth flight. The problem is that there is little difference in the shading of the faces that make up the "mounds". When smooth shading is applied, any resemblance to a 3D feature and any indication of shape is totally washed out (See Figure 1).

Figure 1 3D Static Waves

On military helicopter programs, we investigated many modeling techniques to alleviate this problem. Among these techniques were overly accentuating sun shading, outlining faces in 3D objects, and placing a checkerboard pattern on 3D features. Whereas these techniques can be somewhat accepted by the viewer in terrain (there are regular field patterns in many areas), they are totally unacceptable in an ocean scene.

## Moving 3D Waves

Translating the 3D pattern would not change its appearance (over a static 3D pattern) because the sun angle with respect to the faces would not change. Therefore, several other techniques were implemented. These techniques included rotating the 3D objects, switching 3D objects in and out of the scene (leveling), etc. All were difficult to implement and did not give promise of providing a useful and desirable visual effect even if the implementation were successful.

## 2D Sea State

The first attempts to develop sea state were made utilizing a static 2D pattern. Several different regular patterns were modeled and displayed. Although these pattern types have been tentatively accepted for nap-of-the-earth flight, their regularity makes them disconcerting for expanses of water. Originally it had been assumed that the patterns could be modeled with subtle differences in intensity so that the appearance would not be objectionable but the eye is much too sensitive to even slight intensity changes, particularly along straight lines between faces. An example of a non-smooth-shaded regular pattern with many intensity levels is shown in Figure 2.

Figure 2 Ocean Surface
(Without Smooth Shading)

These patterns were also modeled so that they could be smooth shaded. That is, the intensity between faces was extrapolated along each display scanline to eliminate the sharp discontinuity in intensity from one face to the next. It was presumed that this "smoothing" in a 2D pattern would be sufficient to give an adequate visual impression of ocean surface.

The pattern of Figure 2 was smooth shaded and is shown in Figure 3. This is obviously an improvement over a non-smooth-shaded sea state. However, the scene appeared much too static and lifeless to properly convey an ocean surface. For this reason, it was decided that a method of changing the apparent intensities of the ocean patterns as a function of time would be necessary.

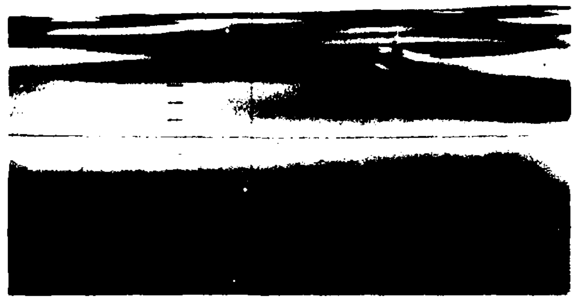

Figure 3 Ocean Surface
(With Smooth Shading)

## Dynamic 2D Sea State

The basic approach in generating a dynamic sea was to model a pattern of smooth-shaded faces with modified vertex normals. Since the cross-product of the vertex normals and the sun vector controls the shading of the faces, many different patterns can be generated by modifying vertex normals while the contrast of these patterns can be increased by moving the sun downward from the zenith. The latter is shown clearly in Figures 4, 5, and 6. Figure 4 was taken without a sea pattern and Figures 5 and 6 show the contrast of the smooth-shaded sea pattern at two different sun angles.

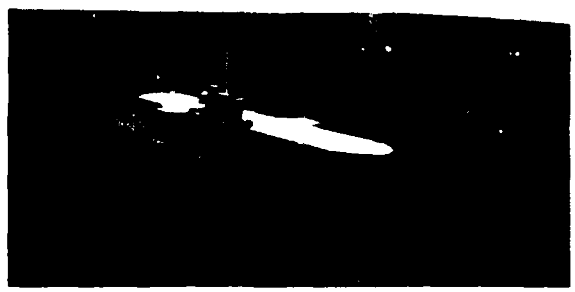

Figure 4 Sea State 1
(No Pattern Contrast)

The initial implementation of this approach was to modify the vertex normals in the object descriptions of the sea pattern in a predetermined sequence. This would cause the faces to change in a cyclic sequence. It was determined that it was necessary to update the normals at display frame rates to prevent noticeable stepping between patterns.

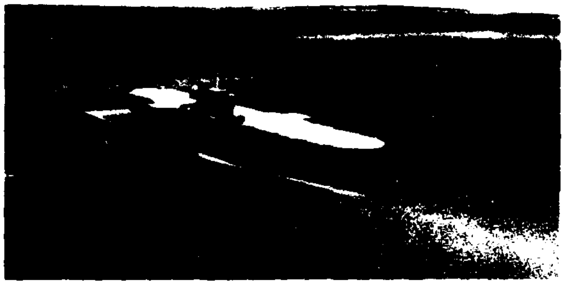

Figure 5 Sea State 1-2
(Moderate Pattern Contrast)

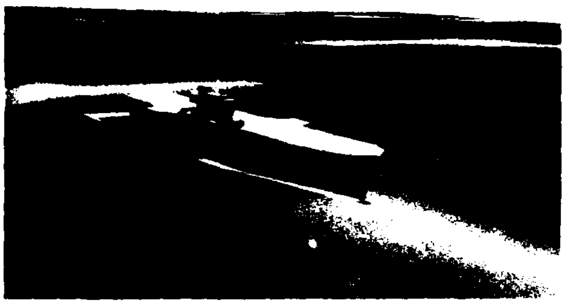

*Figure 6 Sea State 2-3*
(High Pattern Contrast)

Updating the normals at frame rates proved to be an extremely difficult software task and the time necessary for its execution exceeded the available Central Processing Unit (CPU) time. A simpler method of implementation was then developed as follows (See Figure 7). A single sun vector is normally sent each frame for all objects in the data base. By separating the objects for the sea pattern, it was possible to assign a second sun vector for this particular group of objects. Computing only a new sun vector each frame for the entire sea pattern made it possible to achieve the same visual appearance as the original attempt at implementation (updating each of the vertex normals), but with considerably less real-time software. The single sun vector computation for the sea state required less CPU time in the real-time software than in the initial vertex normal implementation. With only one vector to change, it was also possible to use a more complex vector modification algorithm.

The sun vector, when rotated in a circular motion, causes the sea patterns to change realistically. Changing the rotation rate simulates various agitations of ocean surface. Figures 8 and 9 show how the intensity of each square in the sea pattern changes as the sun alters its position as a function of time. The smooth shading was turned off for these pictures

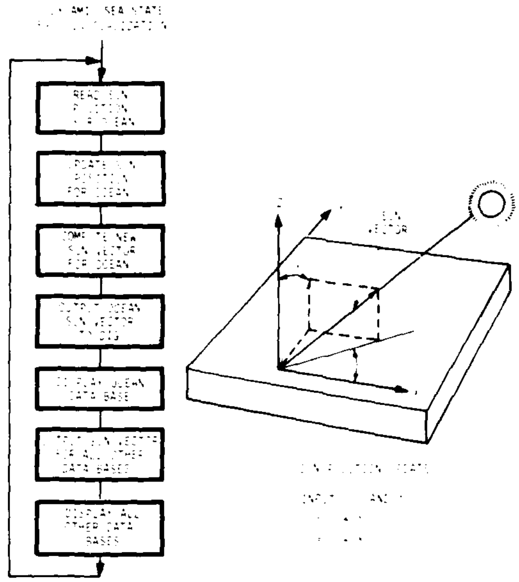

Figure 7 Dynamic Sea State Techniques

Figure 8 Ocean Surface Time $=t_1$
(Without Smooth Shading)

Figure 9 Ocean Surface Time $=t_2$
(Without Smooth Shading)

Figure 10 Ocean Surface Time $=t_2$
(With Smooth Shading)

to make the technique obvious. Figure 10 is the sea pattern shown in Figure 9 with the smooth shading turned on. This effect, coupled with the fact that the angle of the sun vector controls the contrast on the pattern (as described previously) is useful in generating a numbe~ of different sea states.

Three different patterns of vertex normals were programmed and displayed:

1. When the vertex normals ... re assigned in a random basis, the resulting dynamic pattern was that of a confused sea.

2. When the vertex normals were computed as a sine wave on odd rows and its mirror image on even rows, the pattern looked unrealistically distinct.

3. When the vertex normals were computed as a sine wave on all rows, the pattern appeared as a series of bands moving in parallel, not unlike ocean swells.

Of the three patterns mentioned, the random pattern appeared to be the most acceptable visually and was incorporated into the NASA /Ames Digital Visual Simulator.

## BOW AND STERN WAKE

### Face Substitution

In an attempt to generate moving objects such as the ship bow wake, many different schemes were considered. Usually these amounted to a wake moving object which traveled with the ship. Efforts were made to make the complex bow-wave motion using the simplest real-time motion possible. Initial attempts made the moving object in the shape of a cam. As the object rolled about its axis (as it moved with the ship), it would continuously present a different shape (and height above water) to the eye. The implementation of this scheme proved to be quite laborious and required two real-time moving objects (one for each side of the ship) involving many scene edges.

Attempts to simplify the "moving object" procedure indicated that a method would have to be developed that was a radical departure from the straight-forward approach. The movie industry animation methodology was employed and a series of sequenced faces were used to make an object enlarge and decay in a programmed fashion. A procedure was developed whereby all the sequential faces were made part of the moving object with which they were associated--in our case, with the ship moving through the sea. This procedure is shown graphically in Figure 11. Four actual frames taken from the display are shown in Figure 12. As the moving object was transferred from the active data base, one of the bow-wake faces was transferred with it and subsequently displayed. After a fixed number of frames, a pointer would substitute a second face for the first and subsequently display it with the ship. The rate at which the subsequent faces were transferred and the difference between subsequent faces produced the dynamic movement. The selection of these two parameters along with the selection of various colors can be used to produce a wide range of effects.

This technique of effectively modifying the digital data base in real-time gave rise to many of the other effects discussed herein.

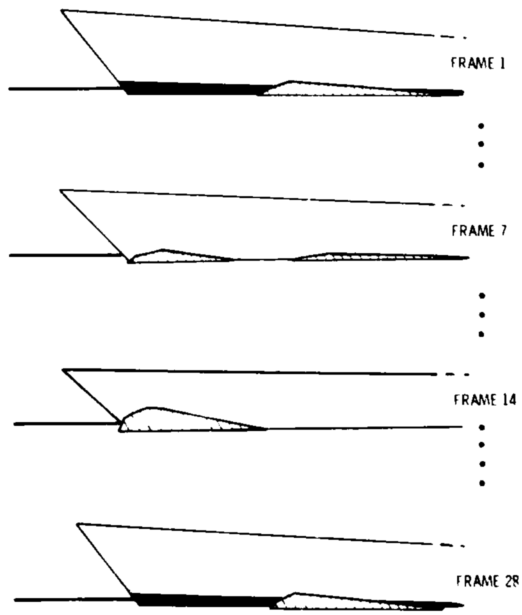


Figure 11 Moving/Growing Objects
(Bow and Wake)

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PROCEEDINGS OF THE 2ND INTERSERVICE/INDUSTRY TRAINING EQUIPMENT--ETC(U)
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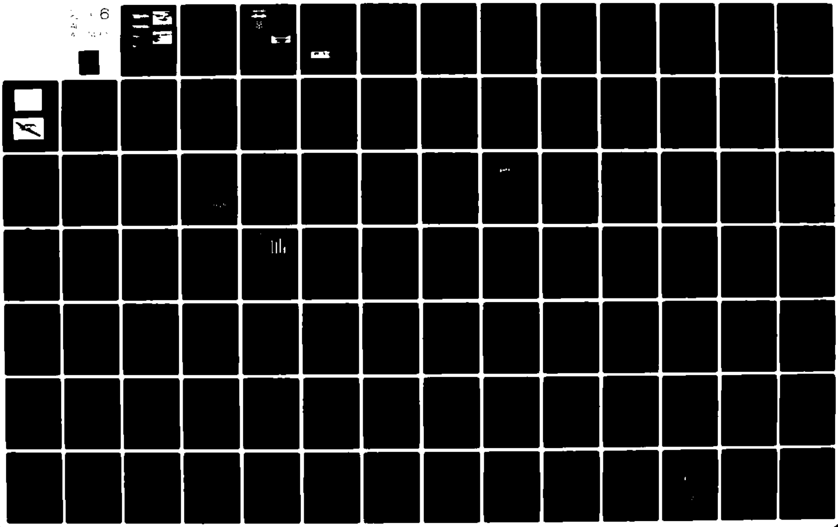
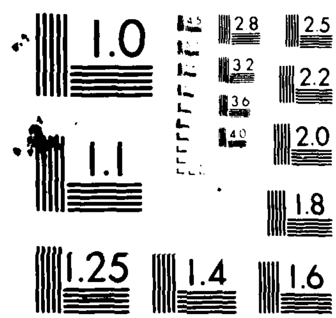





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

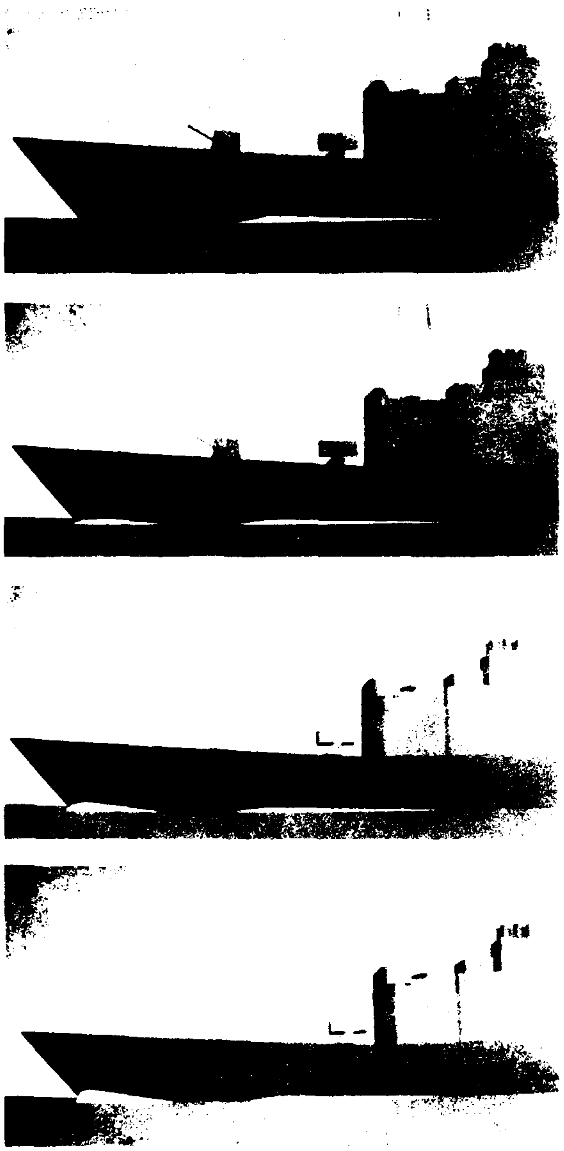
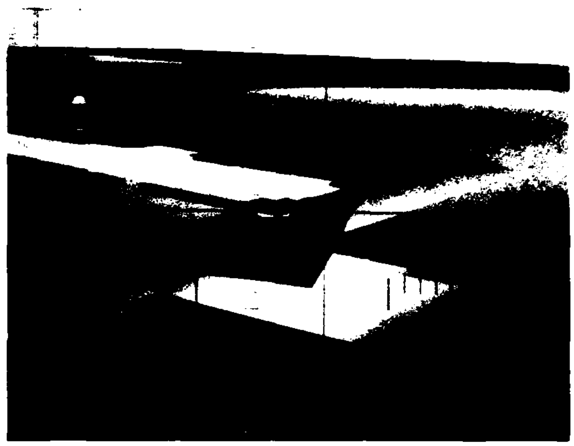
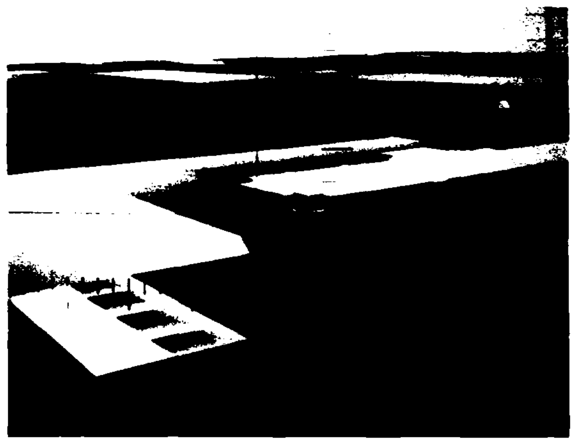


Figure 12 Four Faces (Not Contiguous) of the 28 Faces Comprising the Dynamic Bow-Wake Pattern



Bow and Stern Wake - LPH2 (Without Smooth Shading)



Bow and Stern Wake - LPH2 (With Smooth Shading)
Figure 13

Use of Modified Sea State Pattern

The bow wake generated was extremely realistic when viewed from an eye position close to the surface of the sea. However, when observed from near vertical the faces comprising the bow wake become almost invisible (the faces have no thickness). Techniques to make the bow wake a 3D pattern were complex. It was decided that the design approach used to implement the sea state pattern could also be used for bow and stern wake. Several patterns, pattern colors, pattern sizes, sun vector angles, and sun vector speeds were modeled and displayed on the research simulator. After several iterations when the speed of the sun vector rotation was increased substantially, a "churned water" effect was created. Figure 13 shows the bow and stern wake taken from the research simulator.

## SHIP MOTION

Occulting (Ship/Sea)

The realistic portrayal of sea state demands a substantial amount of ship pitch and roll. Other ship movements, such as heave and sway, are important to landing/takeoff simulation but do not make additional demands on the visual system. Discussions with Navy personnel established that landing and takeoff can reasonably be expected to be performed with pitch less than 5° and roll less than 8°.

The worst case for ship/sea occulting would be from a position close to the ocean surface. Viewed from this position, it appeared necessary to model to some distance below the waterline so that the hull can be seen when the ship is pitched up, and conversely, less hull above the waterline can be seen when the ship is pitched down. This causes a mutually exclusive visual object priority problem. If the ship has higher priority than the ocean, the ship can be seen below the waterline to the point that it was modeled (this makes it appear to "float" on the ocean at the lowest point digitized). On the other hand, if the ocean were to have higher priority than the ship, the ship would not appear except for the area above the horizon. Any occulting schemes that involved paths or seams in the ocean were discarded because they would permit only preprogrammed ship motion. The following is a discussion of the experimental methods.

"Moving Box" Occulting Method. Occulting the part of the ship which is below the water can be accomplished by positioning a box (open at the top) around the ship from the waterline down. The box must be the same color as the surrounding water and must have a higher priority than the ship.

The assignment of color, intensity and priority of the box are easily accomplished. Color and intensity are chosen during modeling. The priority of the box is accomplished by making the box a separate object list and setting its priority during initialization of the real-time program to be greater (lower number) than the ship's parts.

The accuracy of this method decreases with increasing altitude of the viewing point. This accuracy can be maximized by making this box as close to the shape of the occulted parts of the ship as possible. The ship then appears to rise from and disappear into the sea when it actually is being occulted by the moving box.

This method was implemented on the research simulator and is extremely effective. However, a simpler method (using no moving object and fewer edges) is more desirable.

Face Substitution Method. It was originally assumed that if ships were to be modeled only to the waterline (effectively "floating" on the ocean surface), an eyepoint close to the water would detect space below the bow and stern when the ship pitched up and down. Before the modeling of a ship was completed, several methods of occulting other than the moving object method discussed in the previous paragraph were investigated. The most promising of these was a modification of the face substitution method used for the bow wake. Basically, it involved using a series of wedge-shaped faces of progressively larger sizes to "fill" the space between the bottom edge of the ship (waterline) and the surface of the ocean as the ship pitched up, and the removal of the wedge-shaped faces as the ship pitched down. These would be inserted (or removed) in real-time as a function of the angle of pitch (See Figure 14).

(Roll is not a problem because the face used on the bottom of the ship appears to be simply the extension of that portion of the ship below the waterline exposed during roll.)

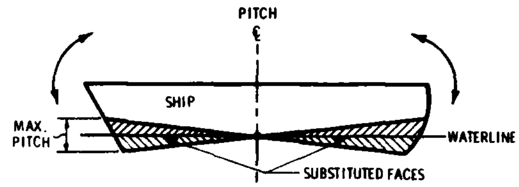



Figure 14 Face Substitution

Necessity of Occulting

When the modeling of a Landing Platform Helicopter (LPH) was completed, it was programmed as a real-time moving object and driven realistically through the ocean data base. Pitch was programmed in as 10° which is double the maximum worst case excursion permissible in landing/takeoff. The LPH in these experiments was modeled only to the waterline. The completed scene was dynamically demonstrated to numerous pilots. At no time during any of these demonstrations was any objection raised, nor was attention called to the fact that when the ships pitched down, the length of the prow did not shorten. In fact, the comments were unanimous that the ships motion was "realistic". The movie that accompanies this paper bears out this contention.

SEMI-OPAQUE IMAGES

Suspension Bridge and Rotor Blades

A technique of substituting visual scene faces in real-time was demonstrated as being feasible and useful in the creation of the bow wake previously discussed. The technique provided a means of generating special effects that achieved a high degree of realism.

The basis of the face substitution procedure was the concept of manipulating the visual data base in real-time. Heretofore, the data base was produced off-line and simply called up when required as various levels of detail (usually as a function of range) or as an entire moving object (aircraft, ship, etc.). The face substitution technique showed how effects that required rapid image movement could be produced easily.

The technique was further expanded to include object substitution as well as substitution of objects/faces on alternate fields or frames to produce a semi-opaque effect. The semi-opaque effect comes about by displaying the entire scene on one field or frame and the object desired to appear semi-opaque on the next field or frame. Since the priority of the semi-opaque object would obscure the scene behind the object only every other frame, the eye would alternately see both (See Figure 15). The effect is the appearance of a semi-opaque object. The following describes how the technique is implemented and some of the interesting effects produced.

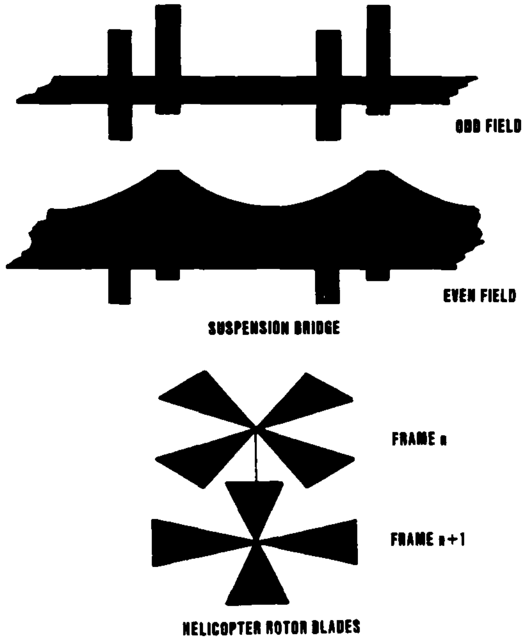



Figure 15 Semi-Opaque Objects

Object substitution is accomplished by modeling the data base with a *dummy object in* the location of the special effect. This dummy object is not displayed but is used for generating planes so that the special effect will have the correct priority. The desired special effect is modeled as a series of objects in the same manner as a cartoon is generated. These objects are then sequentially displayed at object substitution rates dependent upon the particular application.

The suspension bridge is modeled so that during the odd television display fields only the bridge towers and bridge deck are output to the object list (See Figure 16). This permits the scene behind the bridge to be displayed. During the even fields the towers and deck are again displayed (hence appear totally opaque) and the objects that make up the sides of the bridge are also displayed. This gives an excellent impression that the city (or any object) behind the sides of the bridge is only partially obscured by the bridge wires.

An actual image taken from the research *simulator display is shown in Figure 17.* It clearly shows how effectively this technique can be applied.

There is another factor involved here which may not be obvious at first--the repetition rate of the displayed image. In the case of the bridge, the image cannot appear to flicker unrealistically; hence it must be displayed faster than 20 times per second. To accommodate both the update rate requirement and the alternate image requirement, it was necessary to update the digital visual system 60 times per second.

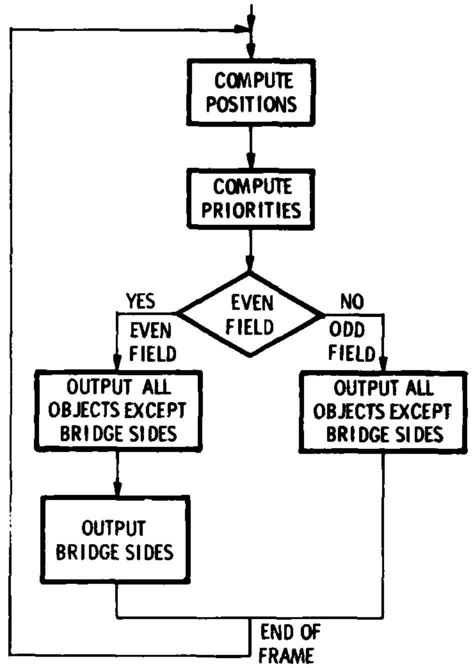



Figure 16 Semi-Opaque Objects (Alternate Field Technique)

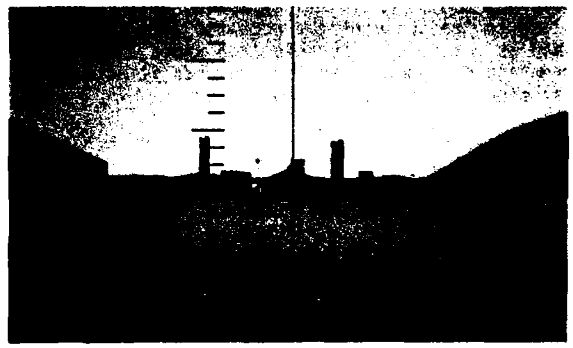


Figure 17 Suspension Bridge

The second example presented here is the helicopter rotor blades. The object substitution technique is used to provide a semi-opaque quality to the spinning rotor blades. It should be noted that in this case two 45° segment German crosses have been modeled so that they are rotated 45° in the data base (providing a complete solid disc) and displayed on alternate frames (rather than alternate fields as in the case of the bridge). The block diagram is shown in Figure 18. This provides the semi-opaque effect as discussed previously. In addition, displaying each set of blades on alternate frames rather than alternate fields as noted previously provided an unexpected effect. The effect of the "flicker" resulting from the 15 image per second update (each blade pattern every other frame) gives a realistic impression of blade movement that was impossible to obtain in any other manner.

In this case, an undesirable attribute of a discrete image system is being used to advantage. Figure 19 shows the semi-opaque quality of the blades, but unfortunately only direct viewing on the display CRT or in a movie can show how this simple technique provides realistic blade "motion".

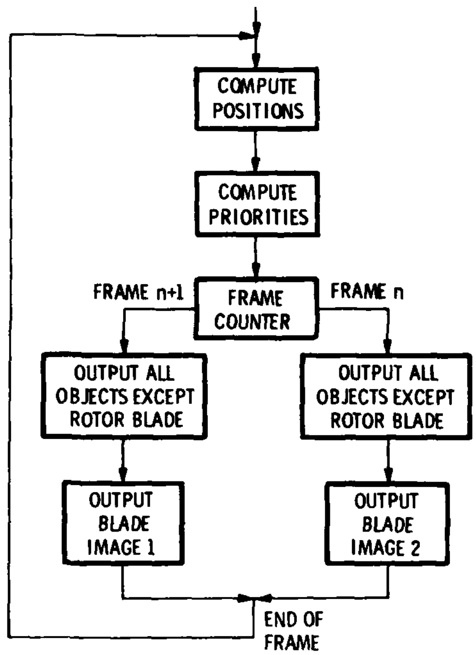



Figure 18 Semi-Opaque Objects (Alternate Frame Technique)

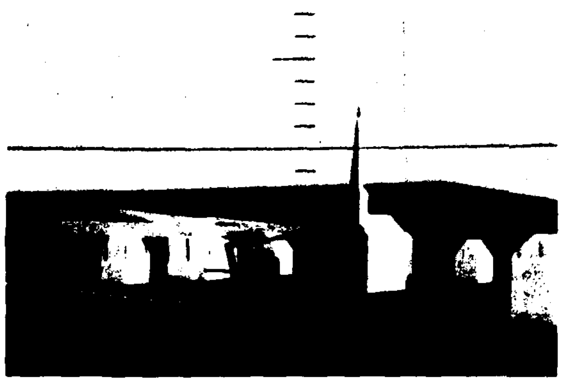


Figure 19 Helicopter Rotor Blades

## CONCLUSION

Two important digital visual techniques have been discussed in this paper. The first was the real-time data base manipulation procedures which were used for producing rotor blades, bow wakes, and weapons effects without resorting to the use of moving objects. The second was the separation of the object list in the data base so that separate sun vectors for different sets of objects could be output to the image processor. In the latter case, the appearance of dynamic sea state resulted from the use of a constantly changing sun vector and a randomly modeled blue checkerboard. The results of the application of just these two techniques are an indication of the kinds of visual effects that remain to be implemented on digital visual systems with little more than imagination.

Both of the techniques used can also be considered successful because little additional data base is required, few additional edges have to be processed, and only an insignificant amount of real-time is required. In these particular cases, it can be stated that the visual impact of the resulting scene is far greater than the small amount of visual system capacity that it uses.

## ABOUT THE AUTHORS

Mr. Frank P. Lewandowski, Senior Scientist, with LINK Division of The Singer Company. In this position he is investigating the possible range of visual effects in digital image generation systems. Mr. Lewandowski received his Bachelor of Science Degree in Electrical Engineering and in Mechanical Engineering from the University of Illinois.

Mr. William Tucker, Senior Engineer, with LINK Division of The Singer Company. Mr. Tucker has been involved with the LINK Digital Visual System since its inception in 1972. He has been instrumental in many of the design innovations which have improved the imagery generated by the DIG. He has also participated in many of the unique data base generation schemes which have resulted in the imagery included in this paper.

Mr. David Hinkle, Senior Programmer/Analyst with LINK Division of The Singer Company. Many of the data base generation and manipulation programs described in this paper are the result of Mr. Hinkle's efforts. Since he joined LINK, Mr. Hinkle has been involved in studies to achieve real-time data base management and new methods for creating edge efficient data base object models.

# VISUAL CUE REQUIREMENTS FOR TERRAIN FLIGHT SIMULATION

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ABSTRACT

Three types of visual scene cues were varied in order to determine their effect on pilot performance during simulated low altitude flight. The three types of visual cues consisted of three sizes of ground texture patterns, the presence or absence of vertical object cues, and the presence or absence of an aircraft shadow. The pilots who flew the simulated missions reported that all three visual cues were useful, however the vertical object cues and texture patterns were more useful than the aircraft shadow. Both the texture patterns and the vertical object cues produced statistically significant differences in quantitative measures of pilot performance.

## INTRODUCTION

The purpose of this study was to assess the effects of three types of visual scene cues upon simulated low altitude terrain flight missions in A-10 aircraft. The three types of visual scene cues studied were ground texture patterns, vertical object cues, and the aircraft shadow. The lack of adequate visual scene textural detail is often considered to be a limiting factor in the use of computer generated imagery for nap-of-the-earth (NOE) flight simulation. Low altitude terrain flight, including NOE maneuvering and contour flight, and aircraft flare and landing seem to require visual scene textural detail for optimum pilot judgment of distance above the ground. The actual level of textural detail required may vary as a function of aircraft speed. For example, it may be possible to use much grosser textural detail for A-10 NOE flight than for helicopter flight. Even with the limited edge capacity of the current Advanced Simulator for Pilot Training (ASPT) system, it may be possible to greatly enhance pilot performance during NOE flight maneuvers, using fairly large texture patterns. Also, by limiting the aircraft altitude and through the use of rolling terrain it should be possible to keep the visual scene edge requirements within the limits of the current ASPT Computer Generated Image (CGI) system. Thus, one goal of this study was to study the effects of maximum visual texturing, within the current ASPT visual system, upon pilot performance during NOE and low altitude contour flights.

Vertical object cues are also quite important for pilots to judge aircraft height above the ground. The relative trade-offs between ground textural cues and vertical object cues will be important in determining the optimum utilization of limited computer generated image edge resources. The relative importance of vertical object cues versus ground texture patterns will also be useful in assessing the utility of CGI hardware options which generate synthetic texture for visual scenes. Thus, simulated missions were also flown with and without vertical object cues in order to study their effect on pilot performance.

The aircraft shadow has also been proposed as an important visual cue for low level flight. Since this visual cue also imposes an additional burden on the CGI system it is important to assess its proven utility as a visual cue for terrain flight. As with the vertical object cues, half of the simulated missions were flown with and half were flown without the aircraft shadow in order to study its effect on pilot performance.

## METHOD

The pilot's task consisted of flying missions in a simulated A-10 aircraft from an initialization point across approximately ten miles of rolling terrain, which consisted of eight valleys separated by low hills that were either 100 or 300 feet high. Twelve A-10 pilots, who were qualified as either instructor pilots or combat mission ready pilots, flew in the study. The flying task primarily consisted of maintaining a very low altitude flight profile consisting of both nap-of-the-earth flight around vertical objects and contour flight which followed the profile of the terrain. Low altitude flight was imposed by instructions to the pilots and by feedback concerning performance measurement scoring. Pilot performance was quantitatively measured in several ways. One primary measure consisted of scoring pilot ability to maintain aircraft altitude at 50 feet plus or minus 30 feet, while flying in the flat valleys. This score was computed as a percentage of the time within the altitude tolerance band from 20 to 80 feet above ground level (AGL). The pilots were also instructed to try to crest the hills at 50 feet. Actual aircraft altitude values were collected at the top of each hill as well as the minimum and maximum altitude while flying over each hill contour. The minimum altitude value attained while flying in each valley was also saved as a data point. Terrain crashes (strikes) were also detected and scored as the cumulative time spent in contact with the ground. Airspeed was also controlled by having each pilot fly the course at 300 knots. Time within tolerance scoring was also used for the aircraft airspeed with a tolerance band of plus or minus 15 knots.

Three types of visual cues, which served as the independent variables, were randomly varied in order to control for learning effects. The visual cues consisted of three different sizes of checkerboard texture patterns, the presence or absence of vertical objects, and the presence or absence of the A-10 aircraft shadow. There were thus twelve unique combinations of visual cues which were randomly presented to each pilot in a unique random order. The sizes of the checkerboard patterns were either 220, 440, or 880 feet on a side.

Each pilot flew the corridor three times for each unique combination of visual cues, for a total of 36 experimental sorties. Six initial sorties were also flown at the beginning of data collection in order to familiarize the pilots with the mission profile and the scoring feedback, and to reduce initial learning effects.

## RESULTS AND CONCLUSIONS

In general the pilots who flew the simulated missions reported that all three types of visual cues were useful, however the vertical object cues and texture patterns were of greater help than the aircraft shadow. Some pilots reported that the aircraft shadow was particularly useful in signaling impeding contact with the ground. The vertical object cues, especially trees of a known height, were subjectively very useful in gauging height above the terrain. The texture patterns were also reported as desirable, but perhaps in a less conscious fashion than the vertical object cues. The pilots reported a definite preference for the smallest texture pattern, which used squares that were 220 feet on a side rather than the larger patterns. They also especially disliked flying over the largest texture pattern without vertical object cues. The pilots also would have preferred more irregular "natural" patterns rather than the highly regular checkerboard patterns.

The quantitative data from this study indicate that both the texture patterns and the vertical object cues produced statistically significant differences in pilot performance. These initial statistical analyses were performed using a multivariate analysis of variance (MANOVA) on several measures at once, with step down analyses of variance (ANOVA's) for the individual variables. The MANOVA probabilities for these two variables were both less than .001. However, only the texture pattern cues produced a significant effect ($p < .001$) on the time within tolerance scoring for altitude in the valleys. The presence or absence of the vertical objects did not significantly effect this measure. The average scores across pilots for the three texture patterns were 64.7% for the 880 foot, 72.6% for the 440 foot and 77.4% for the 220 foot texture patterns. The average score without vertical objects was 70.9%, and with vertical objects it was 72.2%. The texture patterns also produced the only significant effect ($p < .003$) on the average minimum altitude values in the valleys. These average values were 47.0 feet for the 880 foot pattern, 45.5 feet for the 440 foot pattern and 43.0 feet for the 220 foot pattern. The average value without vertical objects was 45.5 feet and with vertical objects it was 44.8 feet.

The vertical object cues had a significant effect ($p < .001$) on the average aircraft altitude (AGL) at the top of the hills. The average altitude without vertical objects was 72.7 feet and with vertical objects it was 63.6 feet. The 63.6 foot average value was closer to the requested 50 foot clearance at the hill tops. The texture patterns did not produce a significant effect on the average aircraft altitude at the top of the hills. The average values were 69.2 feet for the 880 foot pattern, 67.6 feet for the 440 foot pattern and 67.8 feet for the 220 foot pattern. Both the vertical object cues ($p < .001$) and the texture patterns ($p < .001$) produced significant effects on the average minimum altitude values that occurred over each hill. The average minimum altitude values were 47.9 feet for the 880 foot pattern, 45.9 feet for the 440 foot pattern and 40.6 feet for the 220 foot pattern. The average minimum altitude values were 48.2 feet without the vertical objects and 41.4 feet with the vertical objects. Apparently the pilots flew closer to the hill surface when both the vertical objects and the smallest texture patterns were present.

None of the visual cue variables significantly affected the amount of time crashed. In general, this measure was low with some pilots crashing into the simulated terrain more frequently than other pilots. There were also no statistically significant differences, due to the visual cues, in the aircraft airspeed time within tolerance scores.

Based upon the initial data analyses, the textural visual cue variable appears to have a stronger effect on pilot performance in general, than the presence or absence of the vertical object cues. At this point, the meaning of this effect is unclear, especially when it is contrasted with a nearly universal pilot preferance for vertical object cues.

## ABOUT THE AUTHOR

George Buckland is a Behavioral Scientist at the Operations Training Division of the Air Force Human Resources Laboratory located at Williams AFB, Arizona. His current primary research efforts include the conduct and management of research in the area of visual display system requirements for USAF flight simulators. He received his PhD in Psychology from the University of Rochester in 1976, and he is currently serving as a Major in the US Air Force.

# A NEW VISUAL SYSTEM ARCHITECTURE

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## ABSTRACT

A new generation of daylight computer image generation (CIG) equipment, based on technology known as CT-5, employs some architectural concepts that depart substantially from previous practice. A broad range of simulation requirements can be met efficiently by simple, modular configurations of equipment. Some interesting characteristics of this architecture include modularity of resolution and capacity, graceful response to overloads, channel expansion with corresponding total capacity growth, and comprehensive treatment of image quality issues. This paper provides an overview of CT-5 technology and system characteristics relative to visual simulation tasks.

## INTRODUCTION

Real-time computer image generation (CIG) technology, now well into its second decade of active development, continues to be challenged by the imagery that users would have it produce. This is particularly true in the case of daylight visual systems where the real world remains an implicit but illusive standard. Nevertheless, effective training is being accomplished and these successes, along with the increasing economic imperatives of training by simulation, are driving CIG systems into more complex and comprehensive training application with corresponding visual requirements.

The gap between what is feasible and what is desired can be successfully bridged only through an understanding of both the visual system and the training requirements sufficient to merge the two into an effective training device. This has often proven difficult due in part to the fact that visual systems have not been easily characterized and their performance in a given application may be governed by complex, non-intuitive parameters that elude meaningful specification.

Many of the important characteristics of a visual system are a product of its architecture - the organization, algorithms, and implementation structure used to accomplish the image generation process. This paper introduces some visual system architectural concepts that promote the effective coupling and straight-forward application of CIG technology to a wide range of simulation requirements. This visual system technology, known as CT-5, is the fifth generation in a series of continuous tone (daylight) systems. The CT-5 architecture represents a substantial departure from the evolutionary trend of the earlier systems but is based on principles and approaches that developed from a background of experience on both daylight CT and Novoview night/dusk systems.

CT-5 system concepts emerged in response to a need for the simultaneous provision of high image content and quality across a large field of view requiring many channels. A six channel system has been implemented and is operating in excess of its required capacity of a thousand polygons per channel and several thousand polygons total.

A brief system overview introduces the main functional elements in a basic system configuration and describes the general partitioning of the image processing functions. We then focus on certain display processing concepts and examine their influence on overall system characteristics.

## SYSTEM OVERVIEW

Figure 1 shows a basic configuration of CT-5 components that provides a single channel capability at standard (525 line) resolution. The major visual system sections include a general purpose computer, special purpose hardware called an image processor, and a display.

The image processor in this simplest configuration consists of one each of four basic unit types and would occupy two standard equipment racks. The object manager (OM) and polygon manager (PM) units perform system common functions and comprise what is called the viewpoint processor. This term refers to the fact that the image processing tasks performed here relate generally to the entire scene content in the neighborhood of the simulated eyepoint, rather than the particular portions that pertain to individual channels. The channel oriented tasks are performed in the channel processor section by the geometric processor (GP) and display processor (DP) units. The addition of system units to increase resolution or add channels is accomplished as indicated in the figure.

The system is structured as a pipeline of processing units where computing tasks are distributed along a sequence of dedicated computing elements. Figure 1 also shows by means of cross-hatched areas the location of several field buffer memories in the system. These memories are located at strategic points in the structure between major processing functions. One television field time is allocated to transport and process data from one buffer to the next. This allows the processing hardware to operate at its own pace and be designed to accommodate only the average complexity of an image field. An important consequence of this memory - processor - memory organization is that the capacity of each section is proportional to the processing time allotted. The application of this notion to overload management is discussed later.

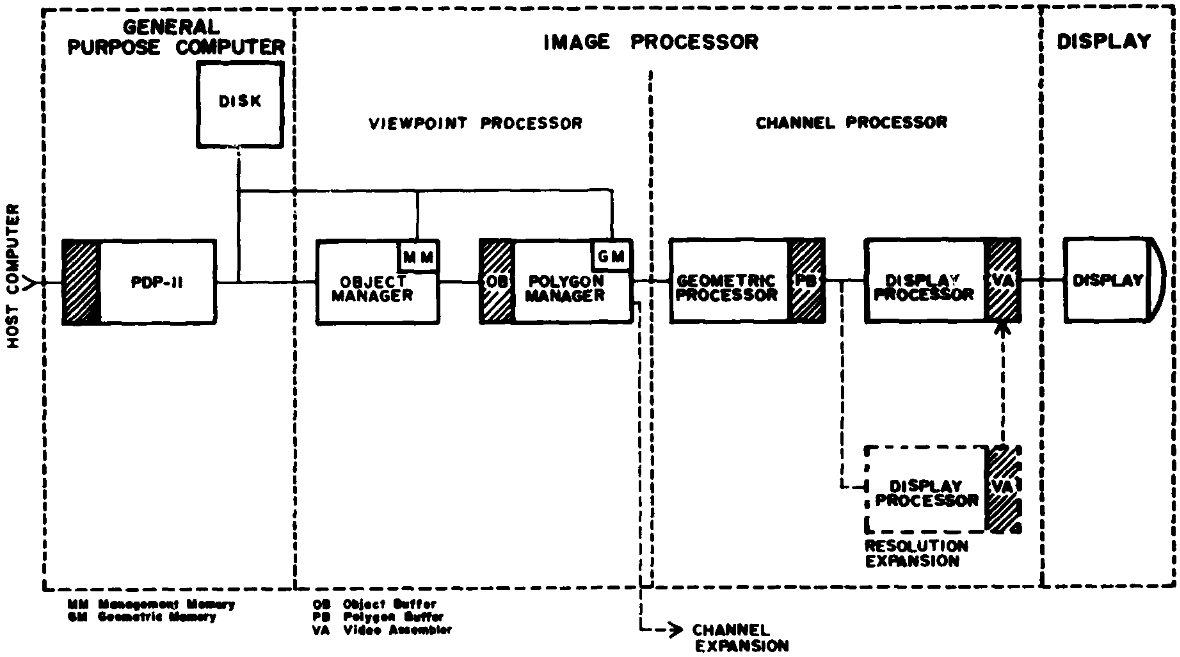


Figure 1. Basic CT-5 System Configuration

The viewpoint processor contains two environment memories that provide online storage for portions of the data base sufficiently close to the eyepoint that they may be required for scene generation. The management memory includes structural information about the data base that is used to accomplish various data base management tasks including the computation of what should be included in the environment memories. Details of the individual scene elements such as point coordinates, polygon definitions, color, etc. are contained in the geometric memory.

In a hierarchical succession of computational steps, the viewpoint processor sifts through the data base to extract a minimal required set of scene elements to produce the current picture. This process includes a sequence of increasingly discriminating tests for field of view inclusion, and the rejection of scene elements that are backfacing or have a perspective size less than a certain threshold. Thus, the scene data provided to a channel processor is a highly refined set that will make efficient use of the hardware in this portion of the system.

Virtually all of the computational power required to generate a television format image in a given channel is contained in the channel processing units dedicated to that channel. Thus each channel tends to be self-supporting and does not interact with other channels.

The GP unit performs all computations involved in transforming the incoming model space description of scene elements into a two-dimensional perspective image in display space. These steps include the processes of rotation, clipping, and perspective division. The result of this process is that an image plane description of all scene elements that project on a display channel is stored in the polygon buffer. The remaining steps to generate a final image are performed in the DP unit and these are described in some detail in the following section.

## DISPLAY PROCESSING CONCEPT

Display processing encompasses the entire set of operations necessary to convert image plane descriptions of individual scene elements into a composite picture with hidden portions removed, anti-aliasing techniques applied, and TV formatting accomplished. These functions generally account for a substantial part of the hardware of real-time CIG systems, and their implementation plays a major role in determining critical performance characteristics.

Historically, the scanline nature of the display has strongly influenced the design of display processing hardware. Not only are the pictures drawn in raster format, but the traditional architectures tend to compute images using scanline notions as the conceptual basis for implementation. Thus, one generally finds that images are computed in scanline order, hardware is partitioned to accommodate scanline image requirements, and video signals are derived from sample points obtained by intersecting scene elements with mathematical scanlines. These notions, although quite natural in view of the ultimate format of the video, have seriously limited the capacity and image quality of CIG systems.

CT-5 abandons the scanline approach to picture computation. Images are computed in feature-sequential order rather than in scanline order; area processors replace scanline processors; and area representations replace scanline samples. The basic concepts and characteristics of this approach are described in the following sections.

## Area Computation

Image processing is performed by hardware which operates in parallel on regions of the display called spans. A span is a rectangular area in image space containing an array of picture elements. The display plane is divided into a contiguous set of these span areas that can be thought of as a coarse pixel set.

Individual scene elements, such as a polygon, are processed a span at a time by sequentially examining the involved span areas, as indicated in Figure 2. The span processor is capable of handling the most complex geometry that scene elements can generate within a span. Two important properties of this parallel processing approach are discussed below.

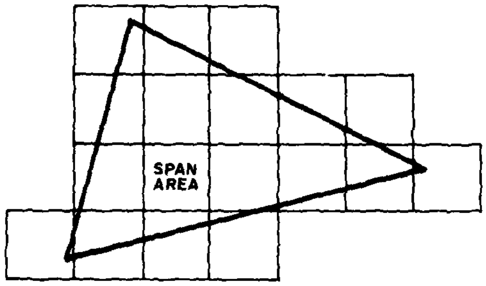


Figure 2. Span Area Processing

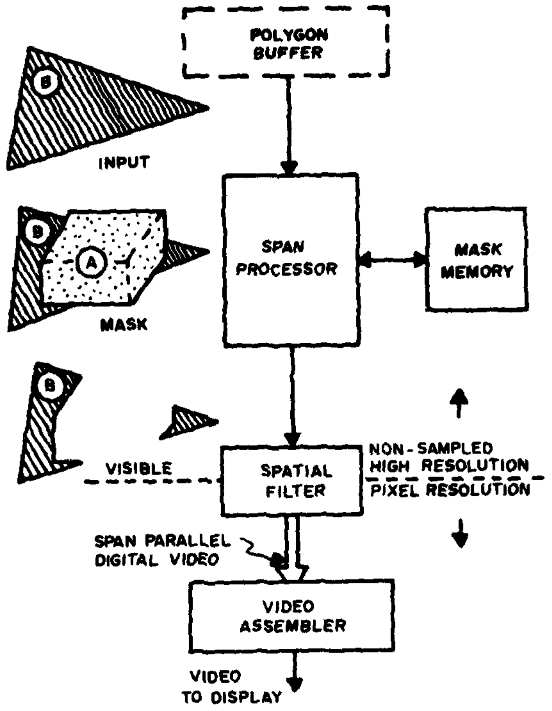


Figure 3. Display Processing Concept

The time to compute a span for a given scene element is not a significant function of the complexity of the scene element internal to the span. Looked at another way, the time required to process a scene element is proportional to its image size.

The approach avoids sampling operations. The image processing algorithms operate on analytic descriptions of the scene geometry to produce high resolution area representations that preserve the essential characteristics of the original continuous image. By retaining image data that includes information about the size, shape, and location of image details at a resolution significantly higher than the pixel resolution, is is possible to produce an anti-aliased image of excellent quality.

## Image Formation

Recalling that image areas are handled in span-sized pieces, one can see how the principal processing functions are accomplished by refering to Figure 3.

Three memories participate in the process. The polygon buffer contains image plane descriptions of all scene elements (such as polygons and lights) that are to appear in the final image. The scene elements are arranged in order of decreasing visual priority so that early submissions to the span processor may occult later ones. This dual memory is updated at the field rate during normal dynamic operation, but either side contains all information required to produce a complete television picture, including both fields.

The video assembler is a dual video field buffer with storage for red, green, and blue components at pixel resolution. One side of this dual buffer supplies digital video to the display while the other half is used to assemble the next field. The assembly side of this memory is structured so that access is available simultaneously to span-sized arrays of pixels, with provision for combining new data with data already in memory.

The mask memory is used to store a high resolution composite record of all prior image regions processed in a field. Only the geometric details delineating existence or absence of scene data are stored.

Now visualize the processing of a polygon through the display processor structure by examining the image sketches accompanying Figure 3. Assume that several polygons, collectively labeled "A", have already been processed. The mask memory would contain the description of the region covered thus far, while the video assembler would contain the contribution to final video attributable to these polygons (including visibility, illumination, and other effects).

Imagine that a new polygon, "B", is submitted to the span processor. Starting with the first touched span, an analytic description of the portion of "B" included in that span is formed while a corresponding description of images already processed is obtained from the mask memory. The data for "B" and the mask memory data (shown as "A") are combined to form two new image descriptions: B + A and B - A. The image B + A (inclusive OR) is the new composite mask that is stored in the mask memory. The difference image, B - A, is the visible portion of B that is passed to the spatial filter section. Here, the high resolution geometric description is recombined with its associated shading data and the result is spatially filtered to derive anti-aliased video data at the pixel resolution.

The output of the spatial filter section is digital video, in span parallel format, that represents the video contribution to be made to the scene by the visible portion of "B". The video data are added to the previous contents of the video assembler. The processing continues in this manner for each touched span until the polygon is completely processed.

## Anti-aliasing

Several important concepts are embodied in the anti-aliasing techniques used in CT-5. The image presented at the input to the spatial filter is a faithful, high resolution rendition of the desired image, including the effects of visual priority. All imagery is treated identically, without complexity limits, and without directional biases related to raster orientation. The image description has the desirable property that a scene produced by complex layers of occulting polygons will be identical to that produced by an equivalent input of polygon tiles forming the same image, but with no occulting involved.

Spatial filtering is performed at the pixel level as indicated in Figure 4. The scene submitted to the filter includes all effected areas of the screen regardless of which field is currently being produced. Thus, filtering may extend to areas outside the current field. Video for each pixel is computed by convolving the visible scene portions near the pixel of interest with a two dimensional filter function. The filter chosen is approximately two pixels wide and is shaped to satisfy a criterion succinctly stated by A.C. Erdahl: "The total energy contributed to all display pixels by a scene fragment should remain constant and be independent of its position relative to the pixel structure." This condition implies that the average luminance of a small region of the display in the vicinity of some particular scene details is invariant under motion of the scene with respect to the raster structure. A filter meeting this criterion and providing adequate bandwidth control and phase response has been implemented. It produces images with high subjective resolution and sharpness while smoothly attenuating the higher spatial frequencies.

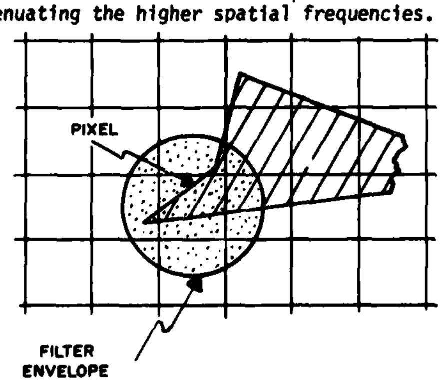

Figure 4. Spatial Filtering

## Capacity Characteristics

As noted earlier, the processing time for a scene element is proportional to its image area. It is interesting to examine the relationship between processing time and incremental image complexity, given a basic image that we wish to embelish.

We can increase the richness of a given scene in two principal ways. One way is to increase the detail of an existing object. The image area of the more detailed object will be about the same as the lower complexity version. It is not quite correct to conclude that the high detail object requires no additional processing time. The increase in time that does occur, however, is primarily related to the fact that we are now processing smaller polygons which are less efficiently contained by the span areas. Therefore the total number of spans processed increases somewhat. However, the processing time grows much more slowly than does the polygon count. Thus, one finds that increasing polygon counts that are attributable to increased detail in existing scene elements, are accompanied by less than linear increases in computing time.

The second way to enhance a scene is to add new objects. The addition of objects increases the depth complexity of the picture, i.e. the average number of surfaces encountered at each point in the image. Since we are forming the image from high to low visual priority it is possible to skip over regions that are already completely covered with scene data. Thus, considerable time might be saved by rapidly detecting "full span" conditions. Although this mechanism cannot be completely efficient, enough help can be obtained to significantly reduce the net processing cost of additional objects. The net processing time is the normal computing time for the new polygonal areas minus the savings achieved by more rapid processing of areas now obscured. CT-5 implements such a scheme that realizes substantial savings when hidden areas of scene elements are encountered.

The net effect of the principles just described is to give rise to a capacity vs. processing time relationship that has the general characteristic shown in Figure 5. The relationship appears to be valid over a reasonable range about the nominal system performance. This characteristic makes it very attractive to consider trading field time for image complexity when needed.

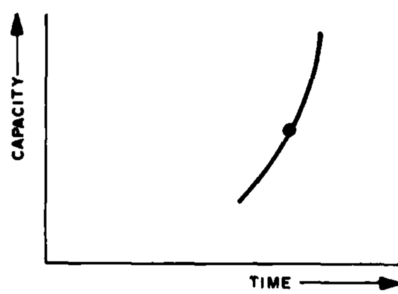

Figure 5. DP Capacity Characteristic

Also noteworthy is the total absence of mechanisms in the display processor architecture that would limit scene complexity. It is possible to generate pictures of arbitrary complexity by extending the processing time.

## RESULTS

The architectural concepts described above lead to some interesting and useful system properties. The following sections summarize the resulting system characteristics that may be of particular interest to those who plan, specify and apply CIG systems.

### Overload Response

Overload in CIG visual systems is inevitable. Regardless of the specified capacity of a system, the user will, in time, exceed it.

The manner in which a system responds to overload is very important to the user. Two systems with the same nominal capacity can prove to be quite different in practice when compared on the basis of effective performance. Some systems are characterized by having absolute capacity limits which are at or near their nominal performance limits. Breaching these limits, even by a small amount, can result in drastic image changes. The only available strategy in such cases is to tune the model so that overload does not occur -- even briefly. This tuning is accomplished typically by limiting model density and by carefully structuring the level of detail transitions to prevent overload - a costly undertaking that generally results in under-utilization of the system.

CT-5 systems automatically manipulate image generator resources to produce controlled responses over a broad range of impending and actual overload conditions. Loads on the order of twice the nominal image capacity can be accommodated frequently without catastrophic losses in the imagery. Thus, the system may be operated at much higher average load levels, and model tuning requirements can be relaxed or adjusted to suit the training mission needs. This fortunate impact on modeling requirements will become increasingly important with the advent of larger and larger data bases as automated modeling techniques are employed and hand tuning becomes prohibitive.

Three principal mechanisms are employed to accomplish load management objectives:

1. CT-5 capacity increases with available computing time. This characteristic, previously described for the display processing functions, also holds for the remainder of the system, where the only limits beside computing time are certain memories, and they are generously sized relative to nominal requirements.

2. Polygons are rejected based on their perspective size. This size threshold can be adjusted to provide continuous control over the number of polygons presented to the pipeline.

3. Overall scene loading can be controlled by level-of-detail selections and the range thresholds at which switching occurs. These thresholds can be changed dynamically.

The general purpose computer monitors load at various points in the image processor and also controls the field time. Under normal conditions the field time is kept constant. Impending overload conditions are sensed and regulated by changing the thresholds on perspective size and level of detail.

If scene conditions should change so rapidly that units cannot complete their tasks in the allotted field time, then the field time is simply extended to provide immediate relief for the problem. Thus the instantaneous penalty for overload is a lower field rate.

Field rate reduction is viewed as a temporary measure to be used while more gradual adjustments are made on level of detail and perspective size parameters. These changes reduce the load by rejecting increasingly larger polygons. Thus the long term penalty is that potentially perceptible polygons are rejected and alternate scene definitions come into use sooner.

At intermediate values of these thresholds it becomes preferable to accept operation at a lower field rate rather than to reject scene details of obvious and useful size. The principal effect of a lower field rate is to introduce the possibilty of perceptible flicker. Field time extension is therefore limited to preclude excessive flicker.

Under still more severe conditions the strategy resorts to frame rate update. This doubles the processing time and capacity for all units up to the display processor. As a final measure, the display processor can resort to a frame rate update cycle with field rate display.

In summary, the overload response of CT-5 is designed to fit the penalty to the crime. The result: graceful overload response and more useful imagery on the screen more of the time.

### Image Quality

One of the principal objectives for CT-5 was to improve image quality well beyond that available from the best existing CIG systems. Historically, the CT system series has pioneered in this area and substantial progress has been achieved. (1) Our continuing commitment to image quality improvements is based on the following convictions:

1. Tangible benefits in system effectiveness are associated with the production of high quality images with a minimum of distracting visual noise.

2. We are not in any immediate danger of having solutions that exceed the needs.

The CT-5 system approach implements a fundamentally sound and comprehensive solution to aliasing problems by the techniques outlined earlier. In the course of developing and evaluating these concepts we designed a test pattern that was found to be quite descriminating in issues of image quality. A photograph of the pattern as generated by a CT-5 system on a 700 line color display is shown in Figure 6.

The pattern consists of triangles radiating from a common center. The triangles are defined as maximum intensity polygons against a black background. At the periphery of the pattern each triangle is one pixel wide and the space between neighboring triangles is four pixels. The pattern reveals much about system performance.

The first thing to note from the photograph is that there is very little variation in the appearance of the triangular spokes as a function of their orientation. The system tends to treat scene details equally, without directional biases.

The individual spokes are resolvable towards the center well beyond the half-way point. Thus we see that the system is able to consistently resolve detail that measures less than one half pixel in size and the detail appears in proper positional relationship (phase) with similar neighboring elements. This aspect of the pattern indicates that high effective resolution is achieved and that small, generally isolated segments of scene detail can be visually tracked down to fractional pixel size.

The final observation about the test pattern performance is that the spokes blend uniformly into the central region. It is worth noting that the fundamental spatial frequency of the pattern is at the theoretical Nyquist limit of one raster line pair at a point 40% out from the center of the pattern. This is the approximate point at which the pattern blends together. The central part of the pattern maintains a generally constant character and average intensity. Pattern modulation decreases uniformly and no coherent patterns arise toward the central area as would be characteristic of aliased spectra. This propery allows small objects to be portrayed and recede unobtrusively into their background.

One important issue not addressed by the pattern is that form of temporal aliasing encountered in an interlaced display system. The tendency of the eye to track scene motion and cause the field lines to appear to lie on top of one another aggravates aliasing behavior. Although field tracking is a fundamental problem in interlaced displays, the attendent aliasing effects can be reduced by broadening the spatial filter function to include contributions from areas outside the current field. The CT-5 system uses image data from all regions of the screen to form an individual field.

The use of a video buffer that stores image data individually for each pixel has made it feasible to implement other subtle improvements in image quality. Previously, scanline approaches to picture generation have encoded video data as raster line segments that define only linear changes in color components. As a result, anti-aliasing and shading changes due to limited visibility had to be approximated by linear changes in video signals. This approximation is incorrect and troublesome for low visibility effects where it leads to some serious visual anomalies. CT-5, on the other hand, is free from these restrictions since results are computed independently for each pixel. The pixel buffer removes all constraints on the ultimate complexity of the stored image.

## Modularity

The CT-5 architecture provides considerable flexibility to expand the basic system configuration to meet various requirements for number of channels and for TV resolution. Interaction among these expansion options is negligible, allowing one to configure systems without having to juggle complex performance tradeoffs. The hardware additions consist of units identical to those used in the baseline configuration.

Channel Expansion. Channel expansion in CT-5 is achieved by the addition of channel-specific parallel hardware at an early stage in the processing pipeline. These modular system increments provide independent computing capacity for each channel, thus decoupling the performance of any one channel from that of the other channels.

The parallel channel approach used in CT-5 contrasts with the organization commonly employed by most other CIG systems, wherein a single image processing resource is shared among all channels. That architecture minimizes the channel specific hardware, but the available system capacity must be divided in direct proportion to the number of channels served. Thus, both model and scene densities must be reduced as channels are added. Furthermore, secondary system constraints such as edge crossings per scanline or total segments often remain constant with increasing channels and become serious limits when applied to the composite of all channels.

The CT-5 approach was motivated by a desire to serve efficiently both single channel requirements as well as wide field of view, multi-channel configurations, without having to sacrifice scene density. In operational terms this means that a model designed for a single channel CT-5 system will also be of about the right complexity for a multi-channel system.

Having independent parallel channels has other advantages. For example, the conduct of simultaeous independent simulations with one CT-5 visual system is possible without the danger of unpredictable interactions among the simulations. CT-5 is designed to accommodate a variety of other special requirements of this type. Independent channels also greatly simplify fault isolation and make it highly probable that failure effects will be confined to a single channel and allow training to continue on the remaining channels.

Resolution. Increased raster resolution is accomplished by the modular addition of display processing units. The single DP unit used in the basic configuration provides a raster of 1/4 million pixels - equivalent to a 525 line T V standard. Expansion to 700 line resolution has been accomplished and provision has been made to accommodate 1000 line requirements. The relative distribution of available pixels between lines

Figure 6. Aliasing Test Pattern Generated on CT-5

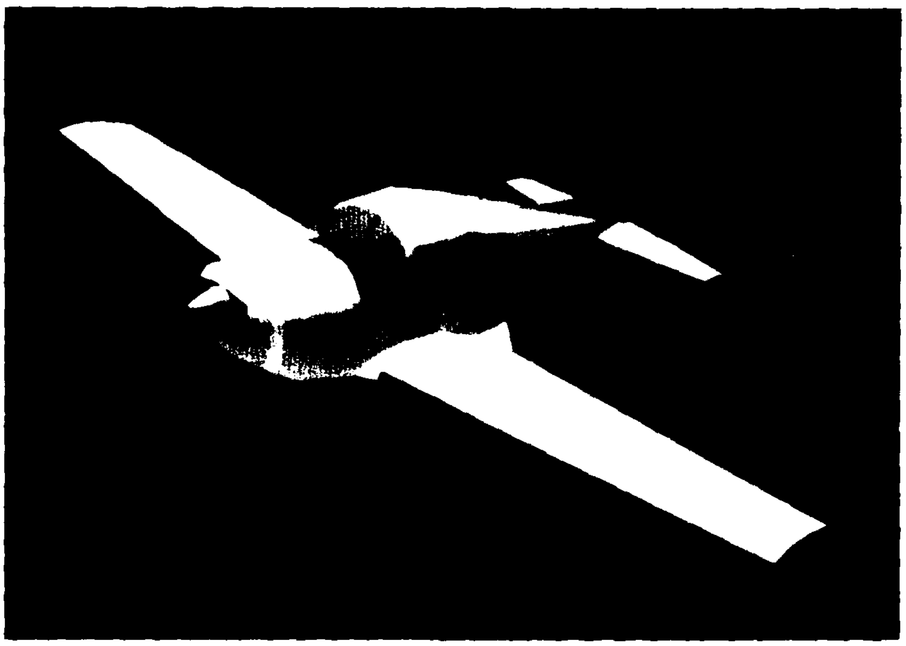

Figure 7. A 180 Polygon Aircraft Scene

and elements is quite flexible, thus permitting a wide variation in the aspect ratio of the chosen display. DP units are designed to operate in parallel configurations that divide the span processing load so that there is no attendent sacrifice in channel capacity as resolution is increased.

In addition to the above advantages, the relative independence of channel processing hardware even permits different scan standards to be used in different channels. This capability would be important in the future if the application of wide angle optics in selected channels prompts the need for high pixel counts in some channels and standard counts in others while preserving consistent scene complexity and image quality across all channels.

## CONCLUSION

A new CIG system architecture has been described. It includes some novel concepts that offer effective solutions to perenial problems encountered in real-time visual systems.

CT-5 applies these concepts in a set of system modules that implement a modular, efficient, and extensible approach to the generation of scenes composed of polygons and lights. These same principles also extend quite naturally to more complex scene primitives and to texture.

Parallel area processing is the central theme in the conceptually straight-forward implementation of display processing functions found in CT-5. The concepts related to area processing are an integral part of the image quality, capacity, and growth characteristics of the system.

The architectural properties that equate processing time, degree of area parallelism, and capacity are perhaps most intriquing. For the present, this has made possible the provision of an extremely elastic overload response within the context of a high basic capacity. In the future, systems will undoubtedly tap increases in either computing speed, parallelism, or both to achieve their goals; and the trend toward simple, repetitive architectural structures will continue with the further application of LSI technology.

## ACKNOWLEDGEMENT

Many individuals contributed to the realization of the concepts described in the paper. I would like to note expecially the significant contributions made to display processor concepts by Mike Cosman, Allen Erdahl, and John Robinson.

This work would not have been possible without the continuing encouragement and support of Dave Evans and Rod Rougelot throughout the development, and the opportunity provided by the U.S. Marine Corps to apply these results on a grand scale to the requirements of the CH-46E visual system.

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## ABOUT THE AUTHOR

Mr. Robert A. Schumacker is Director, Advanced Visual Systems at Evans and Sutherland. He has been active in the development of CIG visual systems for over 15 years and holds BS and MS degrees from the Massachusetts Institute of Technology.

# A NEW APPROACH TO CGI SYSTEMS

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ABSTRACT

A NEW APPROACH TO CGI SYSTEMS: A new approach to CGI visual systems is presented which has distinct advantages over conventional systems. Although conventional systems have provided the simulation community with a high level of sophistication, they are costly and lack the modularity required for low-cost, limited requirement trainers.

The new CGI approach capitalizes on recent advances made in modern semiconductor technology coupled with double-buffered refresh memory, video lookup tables, and modular design techniques. The advantages of this new system (GVS-1) are reduced system cost, minimal development risk, high modularity, and high reliability.

The basic components of this system (general purpose computer, geometric processor, display generator, illumination control) are described in this paper. In addition, texturing capability of the system is briefly discussed.

## CONVENTIONAL CGI VISUAL SYSTEMS

The past decade has been one of rapid growth in CGI visual systems. During this time, two major technological solutions evolved in the form of low-cost calligraphic and high-cost raster scan approaches. The former, developed originally to present simple night landing and takeoff scenes, have been expanded recently to offer daytime scenarios. They are, however, still basically low capability systems limited in scene detail and number of colors. The latter, created to meet much more demanding training requirements (high detail with full color), have achieved a significant level of sophistication. These systems can produce realistic pictures of man-made objects (which can easily be represented by edges) and somewhat less realistic images of natural terrain and vegetation. Unfortunately, the price of conventional raster scan systems is such that only a few trainer applications can justify their use. This high cost, which is a direct result of their complexity, can be attributed to the level of technology available at the time of their initial development.

The basic concept and design stage of conventional raster scan systems occurred a number of years ago, when the lack of fast and inexpensive mass storage devices precluded any method incorporating intermediate digital storage of the entire screen image. This, in turn, forced these systems into defining the image "on the fly" in synchronization with the raster TV display, and placed an enormous computational burden upon the system design. Not only was there the obvious requirement of defining which objects should appear on the screen, but also in which order these objects should appear in terms of the left-to-right, top-to-bottom raster format. This ordering, or sorting, was the primary factor leading to the high complexity and cost.

## THE NEW APPROACH

The recent advances made in semiconductor technology have resulted in the opportunity to design and construct a CGI raster visual system in a completely new manner. The availability of cheap, fast, and dense mass storage devices, combined with the derivation of new algorithms implemented in hardware and firmware, has allowed this technology to be applied in an extremely efficient manner.

All raster CGI systems perform scan conversion, the process of converting a picture image into lines and picture elements for presentation on a TV screen. Unlike conventional systems which perform this function by multiple sorting operations, the use of double-buffered image memories allows the scan conversion to be accomplished by merely reading the image out in a raster order after it had previously been stored in a convenient random fashion.

The Gould Visual System, GVS-1, developed at Gould Simulation Systems Division, is the result of this progress and embodies both the simplicity and low cost of calligraphic systems and the high performance of conventional raster scan systems. Among the advantages of the GVS-1 are:

- Simplified architecture and standard parts
- Less hardware and high modularity
- Low cost
- High reliability

The implementation of mass semiconductor storage organized into memory planes plus unique algorithms to make full use of the memory plane approach provides for a simple and straightforward system. Another advantage is the repeatability of blocks where, for example, all memory boards are identical. Thus, a major advantage of the GVS-1 is in its simplified architecture and standard parts.

Less total hardware exists in the GVS-1 than conventional systems, since the use of the mass storage technique, combined with powerful algorithms, has eliminated the amount of components required to perform the necessary CGI functions. High modularity, a primary design criteria, was achieved as a direct result of the simplicity of the system, and provides ease of interchangeability, fault isolation, and maintenance.

Low cost is inherent because of the system's simplicity and low parts count. Low initial costs and low life cycle costs are a result of using semiconductor technology which is continually going down in cost. Therefore, future replacement of parts will be less costly with time. Other systems not incorporating this approach do not have the same cost advantage.

Another advantage resulting from this approach is high reliability. The GVS-1 uses standard grade circuit elements and operates well within the operating range of each of these elements.

GVS-1 SYSTEM OVERVIEW

The GVS-1 visual system consists of the following major subsystems as illustrated in Figure 1.

- General purpose computer
- Geometric processor
- Display generator
- Illumination control
- CRT monitor

The general purpose computer provides the interface between the visual system and the rest of the simulator. It performs scene data base access/retrieval functions and supplies data and control parameters to the other GVS-1 subsystems. These special purpose hardware units calculate and produce the simulated scene for display on the CRT monitor. The geometric processor performs three-dimensional coordinate transformations and defines the instantaneous scene image in a form ready for use by the display generator. The display generator converts the digitally defined scene into RGB video. During this operation, simultaneous write and read operations are performed within the double buffer image memories.

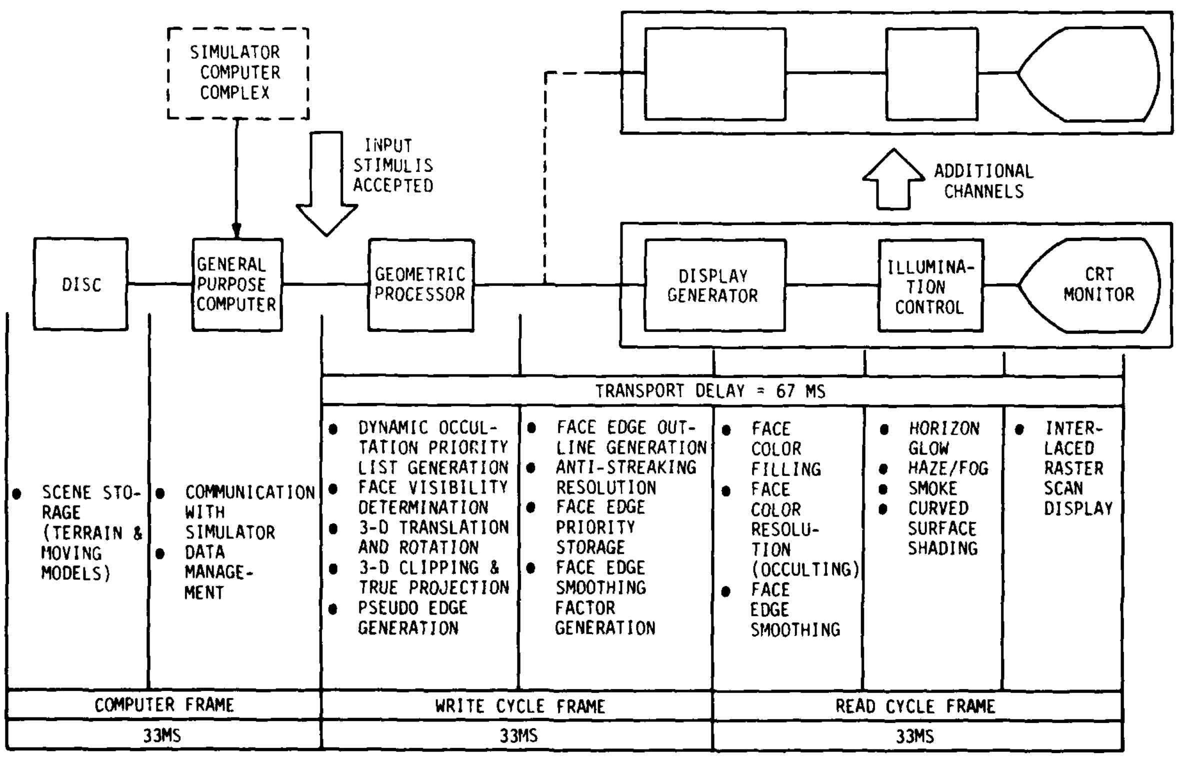


Figure 1. GVS-1 Functional Allocation And Timing

As the data list from the geometric processor is being stored into one set of memory planes, the other buffer (just previously completed) is read and the output scene image resolved and converted to analog video. The final image processing is performed by the illumination control which enhances the scene realism by providing such effects as horizon glow, fading of colors with distance, etc. Finally the completed image is transferred to the CRT monitor for display.

The system performance parameters are presented in Table 1. The modular nature of the design provides great flexibility and modification of many parameters can be accomplished with only simple hardware changes.

## GENERAL PURPOSE COMPUTER

The general purpose computer provides the data and control information for the rest of the visual system as a result of communication with the simulator. It primarily performs bookkeeping functions and is not involved with the real time image geometrical transformantions which are executed in separate special purpose hardware (geometric processor).

## GEOMETRIC PROCESSOR

The geometric processor is the major computational element of the GVS-1 visual system. It utilizes inputs from the general purpose computer and performs all image transformation calculations required to convert three-dimensional scene elements into a form compatible with the display generator.

### General Concept

The geometric processor is a high-speed, parallel processing device based upon large scale integrated (LSI) circuit elements. Groups of these elements are organized into a distributed processing network to accomplish the necessary arithmetic and logical functions. The configuration utilizes two basic computational structures - scalar processors (SPs) and vector processors (VPs). The scalar processors interface external devices, perform general purpose functions and provide data and control for the vector processors. The vector processors perform high-speed repetitive arithmetical and logical operations. Overlapped execution ("pipelining") is used to achieve high throughput rates and to allow the geometric processor operations to occur simultaneously with the display generator image drawing. As a result, image generation in the GVS-1 is a two-frame operation. The first frame consists of calculation and storage and includes both the geometric processor functions and the display generator drawing. The second frame is a reading frame, during which the image is displayed on the CRT monitor. The ability to fully develop and display an image within only two TV frames represents an important feature of the system.

TABLE 1. GVS-1 SYSTEM PERFORMANCE

| BASIC SYSTEM | OPERATING OPTIONS | SYSTEM OPTIONS |
|---|---|---|
| 2000 potentially visible edges (32 pixel average edge length) 1600 visible edges with 1000 light points | Update rate 30, 15, 10, 5 Hz | 640 visible raster lines |
| 20K edge data base | | Number of channels |
| Dynamic occulting priorities | | Curved surface shading |
| 64 instantaneous colors from a color base of 32K colors | | Larger data base |
| Dawn, day, dusk, night scene illumination levels | | Texture |
| Edge smoothing | | |
| Weather - range visibility effects | | |
| Moving models | | |
| Full perspective presentation moving observer | | |
| Four levels of detail | | |
| 512 visible raster lines 30 Hz, 2:1 interlace | | |

## Functional Description

The general purpose computer provides simulated scene data (terrain and flying models) in the form of edge endpoints to the geometric processor. These data are expressed in their own coordinate systems with known relationships to the observer's instantaneous coordinate system. The geometric processor transforms these data to obtain the instantaneous simulated scene in screen coordinates. The geometric processor provides hardware implemented high-speed arithmetic and logic operations necessary for the real time execution of the following algorithms:

- Dynamic occultation priority list generation
- Face visibility determination
- 3-D translation and rotation
- 3-D clipping and true projection
- Pseudo-edge generation

Figure 2 depicts the distribution of these algorithms within the computation structure of the geometric processor.

The dynamic occultation priority list algorithm is performed for all three-dimensional convex solid objects (stationary and moving) which may occult one another. This process is implemented for any portion of the simulated scene which was chosen for viewing at a given frame time.

Dynamic occultation priority lists for stationary objects (mountains, cultural features, etc.) and for moving models' components (aircraft body, wings, elevators, etc.) as viewed by the observer are created separately. Then the occulting powers of the moving models relative to the terrain objects are determined. This allows the merging of the separate priority lists into the total dynamic occultation priority list for all stationary and moving objects.

Face visibility determination is performed to eliminate those faces of the three-dimensional convex solid objects which are invisible to the observer at a given instant of time. All other faces which are visible can, however, be occulted by objects which are closer to the observer. The ordering of these occulting objects is determined by a priority list of dynamic occultation. Face visibility is established by examining the angle between the outward normal vector of the face and the vector from the eyepoint to any point on this face where both vectors are expressed in the

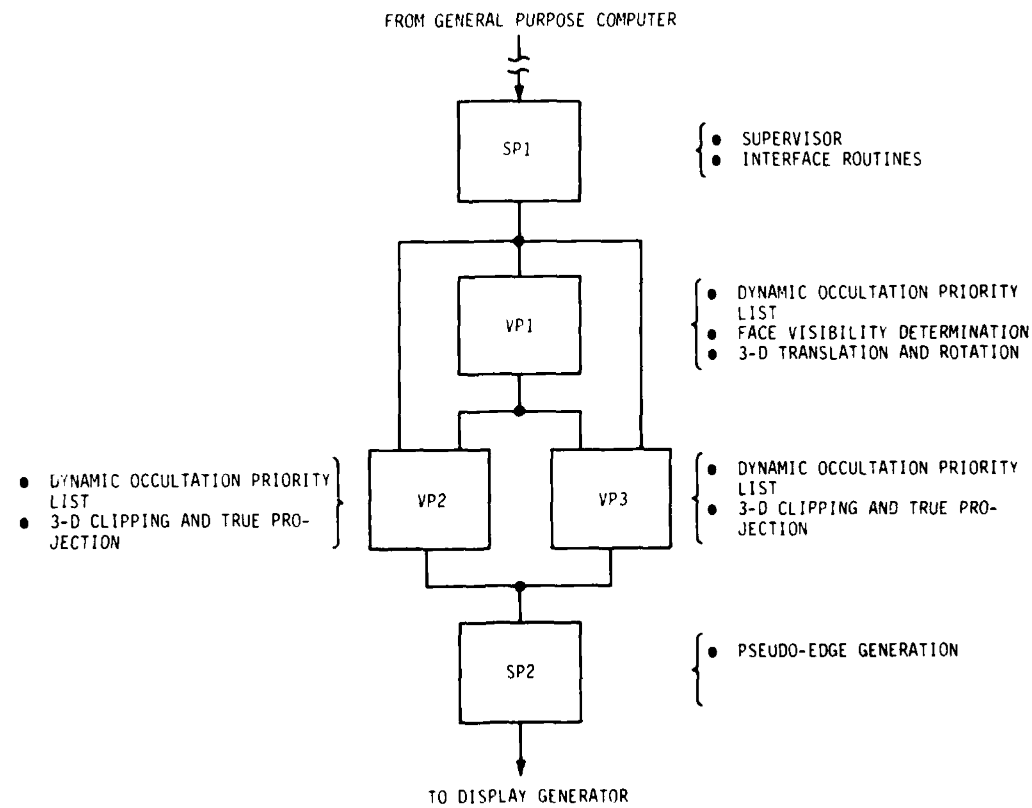


**Figure 2. GVS-1 Geometric Processor Algorithm Distribution**

observer's coordinate system. The face is visible if the angle between these two vectors is less than 90 degrees.

Three-dimensional translation and rotation is performed to transform the terrain and moving models edge points from their own coordinate systems, defined in the data base, to the observer's instantaneous coordinate system. This algorithm accomplishes the translation and rotation for the general case of an observer and a model or models moving independently with respect to a fixed Earth coordinate system.

Clipping is performed to eliminate those edges and parts of edges describing the simulated scene that are outside the observer's instantaneous field of view. Subsequent to clipping, true perspective projection of the image into the screen coordinate system is performed.

After execution of the previous algorithms of face visibility determination and three-dimensional rotation and translation, the simulated scene is defined in terms of connecting points (edge endpoints) whose locations are described in the observer's coordinate system. All invisible faces have already been excluded from the scene and a priority list of dynamic occultation was set up for future execution in the display generator.

Assuming that the viewing window (screen) is a rectangle, perpendicular to the X axis, and located at a known distance from the origin of the observer's coordinate system, a pyramid of visibility is defined with its vertex at this origin. All edges and portions of edges describing the simulated scene outside the pyramid walls on the positive side of the pyramid are rejected as invisible before calculating the true perspective division.

In order to display full color faces in realtime, each face of the simulated scene is automatically painted (filled) by the display generator using left side edges to turn the raster on and right edges to turn it off. Pseudo-edges are generated along the left side of the viewing window for those visible faces which cross the left boundary of the screen. Since the clipping/true projection algorithm removes portions of these faces as being outside the viewing pyramid, these artificial edges replace the clipped-out edges and enable the raster scan system to paint the remaining visible portion of the face correctly.

## DISPLAY GENERATOR

The display generator is the key element of the GVS-1 visual system. It utilizes digital inputs from the general purpose computer and geometric processor and provides outputs of full color analog video. This video is the input to the illumination control where visibility effects are added prior to display on the CRT monitor.

### General Concept

The display generator is based upon the concept of using high-speed random access semiconductor mass storage devices organized in a double-buffer manner. Each buffer consists of multiple "memory planes" composed of these devices. Each memory plane represents a bit map of the entire display screen. The buffers are used simultaneously to store (write cycle) or to retrieve (read cycle) an entire frame of image information, reversing their roles on a frame-by-frame basis. After the retrieval process is completed for a given buffer, its memory planes are clear (all data bits set to zero) and are ready to accept data for the next frame. At the same instant, the other buffer has completed its storage process and is ready to start its read cycle for the present frame. This implementation thus allows new data to be written into one buffer while the other is being read out in synchronism with the TV monitor raster. A functional block diagram of the display generator is presented in Figure 3.

The semiconductor memory planes can be rapidly written into and read out in a completely random manner. The GVS-1 visual system however, utilizes this feature in a specific way. The storage or writing operation is performed in a convenient random fashion, while the read operation is ordered into the required TV raster format. The double-buffer mechanism and separate read and write logic allows for parallel execution of these two operations, resulting in both low transport delay time and high scene detail for a given update rate.

The ability to randomly store the image data and to subsequently retrieve it automatically in a raster order constitutes a significant advantage of the GVS-1 over conventional visual systems of similar performance. It eliminates the necessity of multiple sorting operations and multiple vector generators, and greatly simplifies overload management operations by eliminating such constraints as the limit on the number of edge crossings per each raster scan line, etc. In addition, the separation of the scene development process into two distinct write and read cycles provides new "breathing space" in critical image enhancement operations. For example, in conventional raster visual systems, edge smoothing must be completely calculated and executed within the pixel display time. In GVS-1, edge smoothing is divided into two stages; smoothing information is developed and stored during the write cycle and executed during the read cycle, thus relaxing the constraints on the time devoted to this operation.

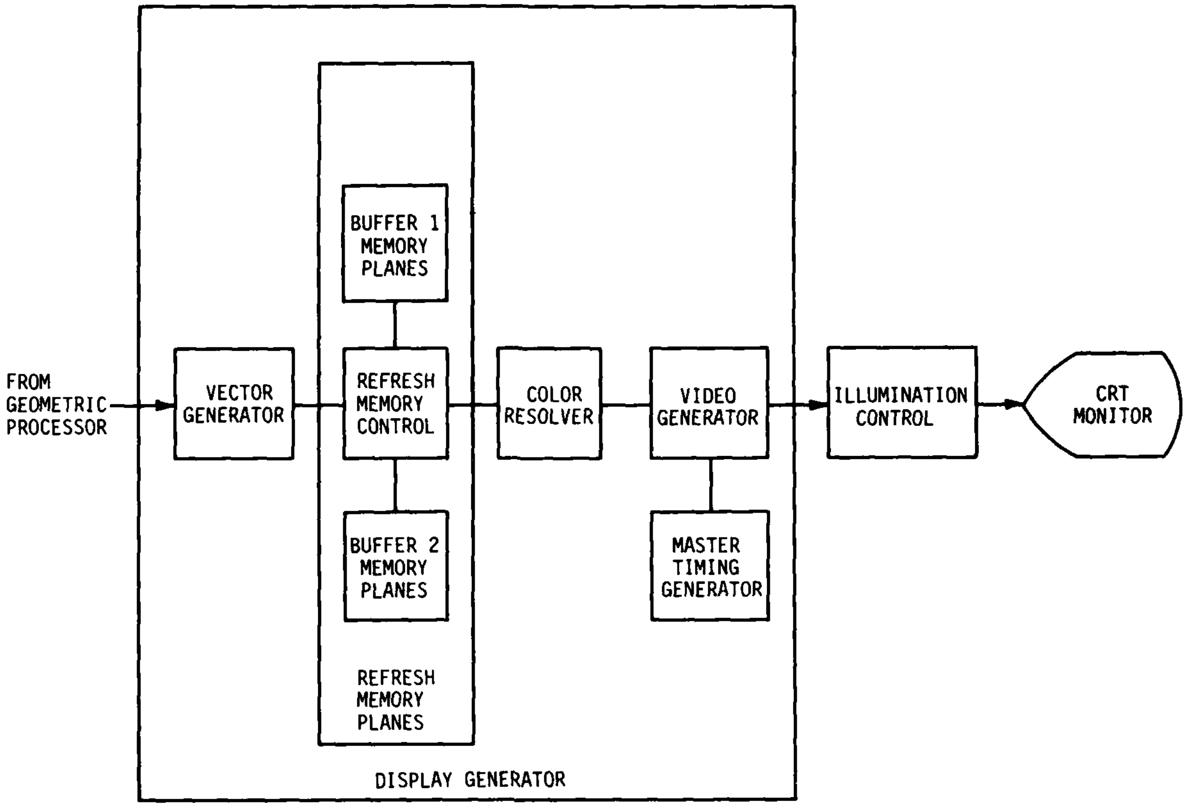


Figure 3. GVS-1 Display Generator Functional Block Diagram

Functional Description

The display generation functions fall into two major categories - write cycle operations and read cycle operations. The two cycles occur simultaneously in separate partitions of double-buffered refresh memory.

During the write cycle a correct geometrical description of an instantaneous picture (corresponding with a given frame) is stored in the selected buffer. The manner in which the information is written into the individual memory planes of the buffer provides the subsequent read cycle operations with the necessary data to display the picture in full color with proper occultation and edge smoothing.

The write cycle operations include:

- Face edge outline generation
- Antistreaking resolution
- Face edge priority storage
- Face edge smoothing factor generation

Face edge outline generation is performed using the scene data list received from the geometric processor. This list contains face edge endpoints expressed in the screen coordinate system with a subpixel precision along each axis. The geometric processor is therefore able to position a face with higher resolution than that of the CRT monitor. The vector generator, working in subpixel increments utilizes this precision when drawing the face edge outline to calculate and store smoothing factors. Combined vertical and horizontal edge smoothing is then executed during the read cycle to reduce the digital aliasing effects of apparent angular rotation, edge crawling, and small surface scintillation.

The vector generator extends a line one full pixel at a time between each pair of face edge endpoints. At each pixel boundary a comparison is performed between the previously stored data and the new edge information. The result of this comparison is the removal of those edges or portions of edges which would cause erroneous streaks of color in the final displayed image. Face edge data that remains allows a simple read cycle mechanism to fill faces with colors. The particular assignment of memory planes into which faces are written determines their relative occultation priorities. During the read cycle, these memory plane assignments are used to resolve the correct output color for overlapping objects.

It should be noted that although the vector generator removes potential streaks by deleting some face edge points, a separate set of memory planes is utilized to insure correct definition of face boundaries. During the read cycle, this information is used in conjunction with the smoothing factor to determine the correct color of pixels representing face outlines.

The smoothing factors are derived by table lookups for each pixel as it is traversed. The method of implementation insures that valid results are obtained for all possible face edge crossings within a given pixel. The resultant smoothing factor represents the area subtended by the highest priority face or group of faces passing through that pixel. This factor is used for the color mixing ratio during the read cycle operations.

During the ready cycle, the digital scene image in refresh memory is converted into analog video. During the write cycle the refresh memory is addressed by the vector generator in face edge outline order. In this cycle, however, the master timing generator addressed refresh memory in raster scan order, exactly as displayed on the CRT monitor. At each pixel, a color is resolved that is either the color of an individual face (no edge exists - face interior) or a color mixture (edge exists - face boundaries).

The read cycle operations include:

- Face color filling
- Face color resolution (occulation)
- Face edge smoothing

Face color filling is the mechanism which fills the area bounded by the face edge outline by turning on all pixels between left and right side face edges along each raster scan line. The filling operation is executed only on memory planes dedicated to storage/retrieval of face outline data, not on those designated to highest priority edges or smoothing information.

Color resolution is the process of determining the output color of each individual pixel. For those pixels containing no edge data, the resolved output is simply the highest priority fill information. For pixels containing edges, additional logic tests are performed to resolve the relative priorities of filling information versus information existing on those planes designated to store/retrieve the highest priority edges. As a result of this, multiple memory plane outputs are determined.

For pixels containing fill information only, the resolved output is used as an address into a video lookup table (VLT). Pixels containing edge data require multiple simultaneous VLT accesses. The output, in either case, is a digital color code representing the video level for each of the three primary colors (RED-GREEN-BLUE). If no edge data exists, the color code is converted directly into analog video (RGB) via digital to analog conveters. If edge data does exist, color codes are mixed according to the smoothing factors prior to the conversion. The mixing is performed as a weighted average of the subpixel areas subtended by the faces.

## ILLUMINATION CONTROL

The illumination control hardware provides the final image processing function prior to the display of the scene on the CRT monitor. Utilizing analog video inputs from the display generation and control parameters originating in the general purpose computer, this device enhances the degree of scene realism by incorporating various visibility effects into the video before it is finally sent to the monitor.

The illumination control unit is an analog/digital hybrid device capable of generating a variety of atmospheric and illumination effects. These effects include simulation of:

- Horizon glow
- Haze/Fog
- Smoke
- Curved surface shading

Control data for these effects are transferred to the device during the raster vertical blanking period. During the display period, these parameters, along with timing and enabling signals from the display generator, are used to modifiy the RGB video.

## HARDWARE

The GVS-1 hardware resides in two standard equipment enclosures. Cabinet 1 contains the general purpose computer, its peripheral, and the geometric processor. Cabinet 2 contains the display generator and illumination control, with sufficient space remaining to allow additional hardware to be added to meet special customer requirements such as texture generation.

## CONCLUSIONS

The GVS-1 is a new, cost-effective CGI system that develops realistic, full color images. The construction is simple, using less components than conventional CGI systems of similiar quality. The system is modular in design allowing quantitative expansion of the number of edges and/or instantaneous colors, and qualitative improvements in the area of edge smoothing.

In addition, the system is capable of accepting the output of texture generators which increase the realism of the scene image. The texturing capability of the Gould Visual System has been successfully demonstrated for an observer having full freedom of motion in azimuth and elevation. In this case, texture has been used on edge-defined faces and independently to develop complex texture objects (e.g. pine tree forest). Texture objects have full occulting power similar to terrain and moving models.

Since these texture patterns are generated and stored offline and read out in real time from a special set of memory planes, they do not interfere with any real time edge operation of the system. As a consequence, the texture patterns can be as complex as required.

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# REALSCAN - A CIG SYSTEM WITH GREATLY INCREASED IMAGE DETAIL

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## ABSTRACT

Computer image generation (CIG) successfully provides images for a large proportion of visual simulation tasks, using polygon models of the environment. However, for close approach to terrain, e.g., for air/ground weapon delivery, confined area maneuvering and harbor navigation, the image detail is insufficient and the cost of generating the high detail data bases is becoming increasingly prohibitive.

The authors are developing a new form of CIG - the Real Environment Algorithm for Line Scanning (Realscan) System, using a uniform grid type digital data base of contoured, textured terrain semi-automatically generated from Defense Mapping Agency (DMA) and stereo photo data. The system will use video disc bulk storage, potentially visible data (for a given position and attitude of the simulated vehicle) being read into random access memory and then addressed in accordance with an algorithm giving correct perspective mapping into the display in real time with automatic elimination of hidden areas of terrain and without aliasing (sampling artifacts).

The image detail in a system of this type can be limited only by the display resolution, giving a very large increase in scene detail over what is likely to be available for many years with polygon modeled CIG. The application of the system to IR is being studied with the aim of producing coordinated visual/IR/radar displays generated from a common data base.

## INTRODUCTION

One of the outstanding problems of visual simulation is the generation of a complex scene. Although satisfactory training can be achieved for many simulation tasks using current computer image generation (CIG) systems at their present stage of development, close approach to terrain in daylight reveals the severe limitations for tasks such as air/ground weapon delivery, confined area maneuvering, low level flight and harbor/channel navigation with both surface vessels and submarines.

With conventional CIG, the environment is modeled by defining the coordinates of points in space, grouping pairs of points to define "edges", connecting edges to form polygons, assigning color and reflectivity to the polygons and disposing them to form polyhedra which approximate the environment to a level limited by the processing power of the real time CIG hardware. The number of edges processed per displayed scene is the usual metric for such hardware with the state-of-the-art currently around 8,000.

For modeling regular objects such as a runway, polygon modeling is economical in terms of the size of data base and the amount of processing hardware. However, a complex environment such as an area of countryside consisting of contoured terrain having detailed surface texture and solid objects such as trees, building, etc. on it, is not realistically reproduced by present CIG systems for two reasons: modeling cost and processing hardware limitations of the polygon modeling technique. Further development in polygon model type CIG processing hardware is in progress by several manufacturers (the "edge war") but the limiting factor is not so much the real time processing hardware as the cost of generating the increasingly complex environment models or data bases required.

## AUTOMATIC DATA BASE GENERATION PROBLEMS

Recent studies (1) at the Naval Training Equipment Center (NAVTRAEQUIPCEN) on the automatic generation of polygon type data bases from stereo photographs showed promise for individual objects but underlined the great difficulty of the problem for terrain. Automating the production of polygon models of real world environments is a task being addressed by the operational equipment community specifically with regard to Cruise Missile guidance systems, and success is not expected for many years.

The reason for the difficulty can be appreciated if one looks at almost any aerial photograph and mentally tries to break it down into separate objects that can be approximated by polygons. Much of what is visible can only be recognized by a skilled photo-reconnaisance technician. The difficulty, therefore, is fundamental: the process, to be automated, requires a degree of artificial intelligence greater (for this task) than that of the average human being. This basic difficulty emphasizes the need for considering the entire image generation system from data base modeling to image display when developing an advanced CIG concept, and for evaluating non-polygon type data bases as a way out of the automatic data base generation problem.

## OUTLINE REQUIREMENTS FOR NEW SYSTEM

NAVTRAEQUIPCEN is currently pursuing an exploratory development program for an advanced CIG system. The aims of the development are:

a. Produce highly complex terrain scenes with detail approaching the limit of a unique scene element for each image display picture element.

b. Allow direct and automatic conversion of real world height, color and reflectivity information into the CIG data base.

c. Provide for large and variable gaming areas from which true perspective scenes can be computed and displayed in real time.

d. Provide compatibility of the new system with polygon model type CIG for optimum flexibility and economy in defining a total image generation and display system.

## DEVELOPMENT OF NEW SYSTEM CONCEPT

If one attacks the requirements individually the following system characteristics emerge. First of all, high scene detail requires a substantial data base; however, the storage requirements are less if two of the ground coordinates are addresses rather than data. Large areas of the world are mapped as uniform grid models, such as the Terrain File of the Digital Landmass System (DLMS) developed by the The Defense Mapping Agency and the ortho color photos produced by the U.S. Geological Survey (2). Models of this type are relatively easy to generate by low-skill processes (as compared with polygon models) and offer the greatest possibilities for use in a CIG system of the type we are considering.

To obtain constant angular resolution of visible details over the display, the corresponding ground resolution required decreases with range from the viewpoint. Since a change of viewpoint means all parts of the data base will at some time be viewed at close range, the data representing the gaming area must all be available at high resolution. However, for any given viewpoint, to avoid having to process, in real-time, high resolution data representing distant terrain, a lower-detail version of the data may be used for distant parts of the scene. This leads to the concept of a hierarchy of resolution levels in the data base, analagous to the levels of detail used in polygon model CIG.

However, whereas the levels of detail in a polygon model data base must all be created by the modeler, with a regular grid data base each level can be derived automatically off-line.

In current real-time CIG systems, following transfer of the polygons forming the scene into the display plane, sorting algorithms are used to produce the displayed image and the processing power required grows proportionally to the square of the detail processed. For systems dealing with a great amount of detail in real time, an architecture is needed in which processing power grows only linearly with detail, and this should be a feature of the new system. To process and display a great amount of displayed detail in real time a modular structure is indicated making use of basically independent parallel processors, each a pipeline.

The use of a ground coordinate grid allows incremental processing in a fixed data base. This feature eliminates the need for floating point operations and repeated need for divide operations. Hence, computationally efficient integer algorithms can be developed which incorporate a pseudo exponentiation upon crossing from one level of the data base to the next (using a step of 2:1 in linear detail between levels).

Finally, the generated image should be in one of the standard television formats, e.g. 1023 lines/frame, 30 frames/sec. This allows existing displays to be used and combined image generation systems to be developed using both polygon and grid data forms of CIG.

## DESCRIPTION OF SYSTEM

REALSCAN (Real Environment Algorithm for Line Scanning) is a concept being developed at NAVTRAEQUIPCEN to produce highly detailed terrain displays directly from a uniform square grid data base in real time. This concept utilizes a hierarchy of resolution levels to model the environment and many parallel - pipelined processors to perform the required visibility determination followed by perspective transformation from world coordinates to display coordinates. The processing is based on computationally efficient integer algorithms.

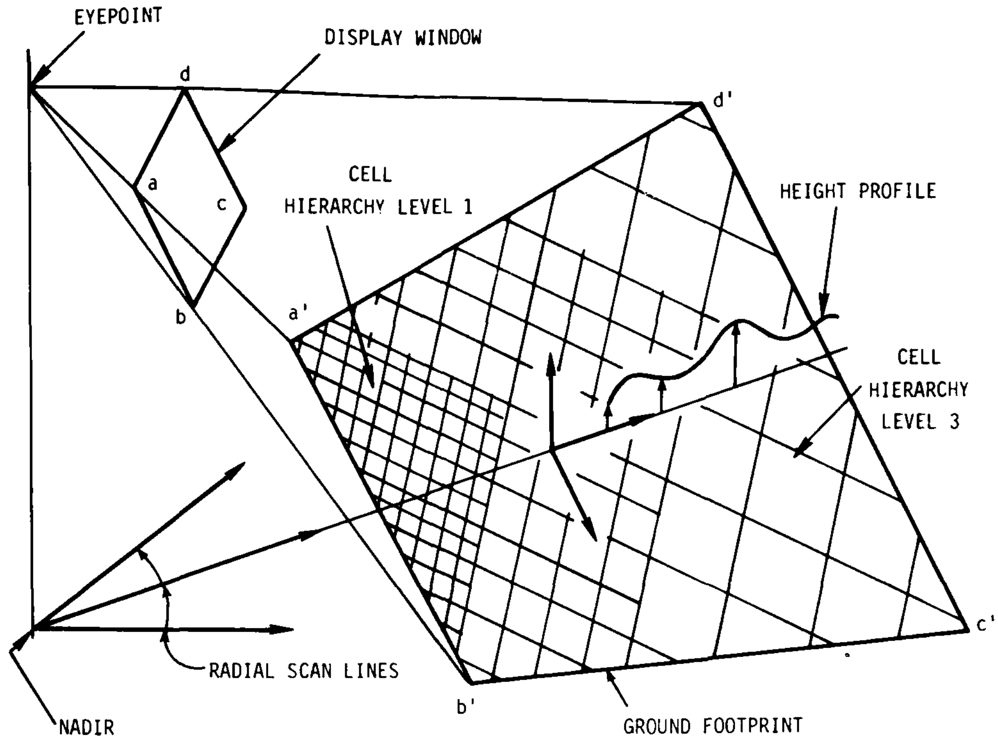


Figure 1. Display Window Projection

Figure 1 shows the projection of the display window on to the ground plane to give the "ground footprint" from which data must be transformed into the display window coordinates. Each level of the data base consists of a square array of "cells", each cell containing digital color and height data for that elementary area of the terrain modeled. Although all levels of the hierarchy are available over the whole gaming area, level 1 is used for parts of the terrain nearest to the eyepoint and levels 2, 3 etc., are used as the range increases. The determination of which points are visible is made by radially scanning the ground footprint in a manner similar to that used in radar landmass simulation. Each radial line drawn from the nadir point (the point directly below the eyepoint) through the ground footprint maps into a line across the display window. As explained later, a frame buffer is used to store the information to be displayed such that the information can be read out in accordance with any standard television scanning pattern for display (e.g. with horizontal scan lines).

New scan lines are initiated through the data base as the scanned distance from the nadir grows, such that the visible part of the data base is correctly sampled. It is necessary, for acceptable image quality, to avoid aliasing (interaction between the regular structure of the digital data base and the regular structure of the scanning pattern which generates spurious detail in the displayed image). The information in each displayed picture element (pixel) must be derived from the data stored in several adjacent cells, in accordance with a weighting algorithm that varies with the position of the pixel in the window. This requires averaging, in real time, of the processed data.

Real time averaging over many cells is impracticable, but the hierarchical data base concept, by providing pre-averaged information, reduces this problem to manageable proportions. Filtering is used to eliminate any remaining unwanted image components.

In transforming data from the ground plane into the viewing window, a perspective transformation has to take place. Each scan line through the data base is dealt with separately, the spacing between image details along the line being changed to allow for the oblique view of the terrain. Details which would be hidden by high ground, are of course omitted from the display.

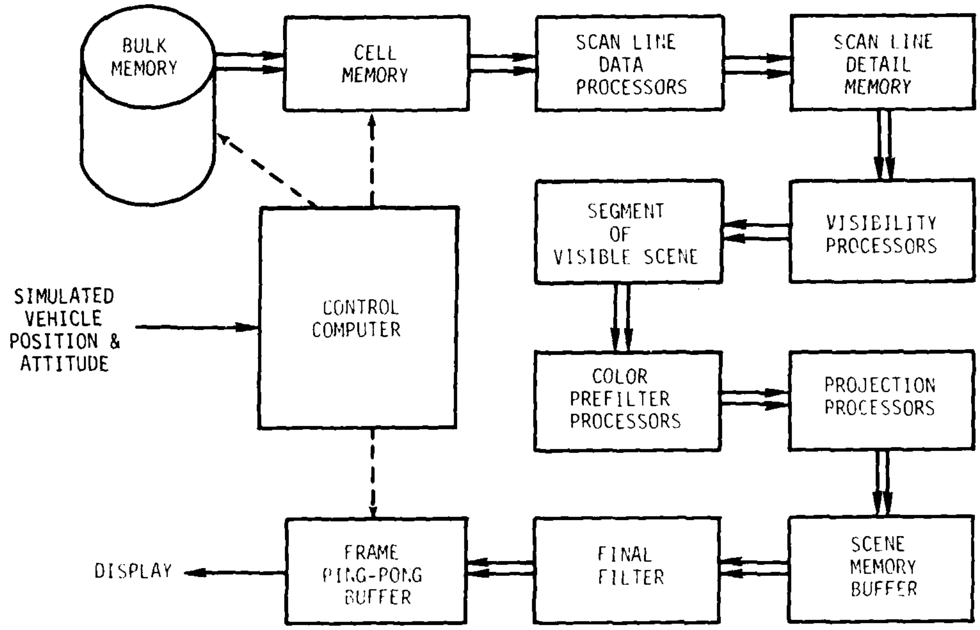


Figure 2. Functional Block Diagram of Realscan System

Figure 2 is a functional block diagram of the proposed system. The color and height data for the complete gaming area are stored in bulk memory; a videodisc is preferred in view of the large number of bits that can be stored in a compact space with reasonably rapid access (this will be considered in more detail later in relation to the generation of the data base). The cost of videodisc bulk memory storage is currently estimated to be $0.10/megabyte as compared to magnetic disc storage costs of $3/megabyte (3).

The control computer accepts simulated vehicle position and attitude data from the host computer and is used to control the flow of data to the Realscan system. For each television frame of picture information, the following processing steps need to be carried out:

a. Obtain observer view point location and viewing direction (simulated vehicle location and attitude) from the host computer.

b. Compute, in the control computer, the viewing pyramid intercepts with the ground reference plane.

c. Use linear and angular rates of the simulated vehicle to predict the potential field of view for future television frames.

d. Determine, using the control computer, which blocks of data representing hierarchical areas of terrain in the bulk memory are to be accessed for generating the required scene, given the nadir point location and field of view.

e. Using the control computer, transfer these blocks of data containing all the information necessary to compute a display of the current field of view plus additional information for future frames, to the "cell memory" (a high-speed, virtually addressed random access memory). After the cell memory has been initially loaded, there is always information available to generate the next frames. The cell memory is then the first stage of a pipeline computational process leading to a frame generation. After the current frame's information is read from the cell memory, those blocks which are no longer in the potential field of view are overwritten by new information.

f. Scan the cell memory using a group of identical scan line data processors. Each processor calculates the elevation and reflectivity information along its scan line using the regular grid data in the cell memory. The radial lines are scanned in parallel groups to minimize the time taken for this process. The data is assembled in the scan line detail memory, data for each scan line being separately stored.

g. Transfer the data, in parallel as needed, from the scan line detail memory to the visibility processor and carry out visibility processing on each line of data. This process determines which parts of the data from the cell memory are to contribute to the displayed scene and which are hidden from view. The algorithm used to determine visibility is similar to that used to determine radar shadows in digital radar landmass simulation systems (4, 5), suitably modified for the hierarchical data structure.

At this stage only the elevations of cell data enter the computation; cell reflectivity/color information is carried with no modification.

h. Accumulate, in the segment of visible scene buffer, reflectivity/color data from the visibility processor in first-in first-out format, to allow for timing variability in the pipeline up to this point.

i. Pass the data from the segment of visible scene buffer to the color pre-filter processor and perform initial filtering along the lines to avoid aliasing while correctly passing sudden luminance changes corresponding to non-aliased edges in the scene.

j. Pass the data from the color prefilter processor to the projection processor where the reflectivity/color data is perspectively transformed from ground coordinates to display coordinates.

k. Pass the output from the projection processor to the scene memory buffer.

l. Perform final filtering using a weighted average processing filter to generate display pixels.

m. Pass the data into a random write/serial read ping-pong frame buffer.

n. Read the frame buffer continuously into the display.

## FEASIBILITY OF PROPOSED SYSTEM

None of the components required for the proposed system is particularly unusual; however, like any CIG system it is complex and will take considerable effort to implement.

The use of a videodisc as the bulk memory has already been referred to. The control computer can be an off the shelf item. The cell memory size is a function of the access time of the bulk memory; for example, an access time of 500 msec. (a design goal for the videodisc system) would require the storage of sufficient data to produce the current television frame plus 29 future frames (assuming a position update of 60Hz). The amount of new information required per frame is a function of the rate of change of position and look direction. With the above access time; a horizontal field of view of $50^o$; a velocity of 100m/second (200 knots); a heading change rate of $50^o$/sec; a high resolution cell size of 0.1m (with appropriate blocks from other resolution levels); the cell memory size requirement is approximately 1 megabyte (assuming 6 bytes/cell). This does not present any special problem.

The scan line data processors need special attention. At this stage of the processing the desired display resolution becomes a consideration in determining how many radial scan lines must interrogate the cell memory. In order to carry out a feasibility analysis, a display having the usual $50^o$ horizontal by $36^o$ vertical format is assumed, with one million pixels. The angular subtense of the diagonal defines the worst case width of the current field of view in world coordinates; in this case $60^o$. From sampling and anti-aliasing considerations, it is desirable to have approximately twice as many radial scanned lines computed as there are displayed pixels across the display for the worst case condition. In this example approximately 3,000 radial scans should suffice.

In principle, 3000 identical processors could be used, all operating in parallel to scan the radial lines. However, the overall throughput delay of the complete CIG system can be kept smaller than that of polygon-type CIG systems with approximately 300 processors each scanning 10 lines. Study is needed to determine the optimum number.

The plan being followed is to develop the processing algorithms for computational efficiency and ease of implementation in modular hardware as a prime consideration. The algorithms have been coded into software and tested in non-real time using the VAX/11/780 at the NAVTRAEQUIPCEN Computer Laboratory. The data base used for initial testing consisted of analytic function generators which simulated a uniform grid of elevation and reflectance values. The extension to operation on a real world uniform grid terrain model for elevation and a digitized ortho-photo of the same terrain area for the reflectivity is the next step. After an evaluation of the non-real time imagery and iterations of the algorithm formulation, a feasibility analysis of a hardware design will be carried out for potential real time implementation.

## THE REALSCAN DATA BASE

The last section presented, in outline, a likely architecture for the system. However, to judge the value of the system it is necessary to relate it to the data base and to quantify some key parameters.

The desired data base form is a hierarchy of two-dimensional arrays of elevation and reflectivity/color. Each array corresponds to the entire gaming area at a specific ground resolution. The size of the data base is a function of the desired ground detail size, the size of the gaming area, and the amount of information stored at each array location.

For example, consider a gaming area of 100 $km^2$, a desired ground detail size of 0.1m, and 48 bits of information stored at each array location. The largest array, corresponding to the highest resolution, would contain $10^{10}$ grid positions or cells and $5 \times 10^{11}$ bits of information. If the cell size in each array is doubled or the resolution is half that of the adjacent array in the hierarchy then the total data base required for the entire hierarchy is (1 + 1/4 + 1/16 + 1/64 ...) times the information stored in the highest resolution array, or approximately $7 \times 10^{11}$ bits for the total data base. Although this is a large number, the optical disc digital storage technology has progressed to the point where such large data bases are feasible. In fact, optical disc storage configurations have been proposed for systems having a capacity of $10^{14}$ bits (6). The next question is: What is the value of a regular grid data base with 0.1m ground resolution? For close approach to the ground, as with a helicopter maneuvering in a confined area landing site, a minimum range from the pilot's eye to ground could be taken as 5m.

Considering a television display with 1000 horizontal scanning lines and $50^{0}$ wide field of view (a typical CIG "viewing window"), the ground resolution (detail size) should be of the order of $\frac{5}{1000}$m or ½ cm. This is smaller than the figure of 0.1m chosen above by a factor of 20. To provide the desired fine detail in the display, the basic concept is to interpolate special functions.

Example of data base construction

a. DLMS terrain file (Level I) consists of an elevation array with a grid spacing of approximately 100m. This array would be interpolated using bicubic functions to form the initial hierarchy arrays. In the case of a desired 0.1m ground detail the number of arrays generated would be 10 corresponding to cell sizes of 0.1, 0.2, 0.4 ..... 25.6, 51.2m.

b. The enhancement of the elevation models can be carried out in a variety of ways. By making use of the DLMS cultural file, generic cultural features which have been stored in a feature library in the gridded elevation format at the various resolution levels can be added to (or subtracted from) the initial elevation data. The generic models can be obtained by photogrammetric techniques using stereo photos of representative real world cultural features.

c. Reflectivity/co information can also be generic or specific. :.is information can be derived from digitized/quantized color ortho photos. (An ortho photo is a product of automatic analytic stereo photogrammetric equipment in which the image displacement due to relief is corrected). If the reflectivity/color model for a specific $100km^2$ area is desired, approximately fifty color aerial photographs would be required to obtain the raw reflectivity photographic data to 0.1m cell size. If the generic route is chosen, appropriate color orthos photos of representative cultural features are utilized to form a library which corresponds to the generic elevation library.

d. The high resolution reflectivity information is interpolated to form the reflectivity data for succeeding lower levels in the hierarchy. In this way scene compatibility across hierarchical levels is ensured.

e. In addition, elevation and reflectivity/color function codes can be assigned to each cell. These codes describe the fine detail referred to in b. above and provide for blending of reflectivity/color and terrain height between cells so as to avoid discontinuities. This scheme enables the aim of making the system generate as much detail as can be displayed to be achieved without excessive memory, although individual objects cannot be dealt with in this way. Further elaboration to the system shown in Figure 2 is, of course, required.

The net result is a highly automated data base modeling system which is not dependent on subjective decisions by the modeler and can be implemented using available data and technologies in the photogrammetric community.

The concept of essentially overlaying a digital elevation model with photographically derived reflectivity data to form an environment model is not new (7) (8) (9), but the use of such a model in a real time CIG system has not been attempted to our knowledge.

The reasons for pursuing this approach to environment modeling are summarized as:

a. The need for efficiently produced low cost, highly detailed environment models.

b. The availability of equipments and technologies which can produce highly detailed environment models in a uniform grid format.

c. The availability of technology to store and access large amounts of data.

d. The feasibility of an automatically generated level of detail hierarchy which greatly reduces computational processing load, since simulated long ranges utilize coarser levels of the hierarchy.

The environment model described has been initially restricted to terrain surfaces which are single valued in elevation, and the acceptability for training using such a model has not been evaluated. However, the potential for extension to multivalued elevation and vertical surfaces has been considered and various algorithms for implementation are being evaluated to represent multi-valued elevation features such as clouds (10).

## THE USE OF THE REALSCAN CONCEPT IN SIMULATION

As already indicated, the proposed system can generate a perspective scene in any television format and so is compatible with polygon model CIG. In fact, its likely eventual use would be in a visual system having a Realscan-generated contoured textured terrain with polygon-modeled target vehicles and buildings.

The generation of irregular objects such as trees remains a problem for polygon CIG although various approaches are being investigated. An adaptation of Realscan may be of value here, using automatic generators of a digital model from a physical model.

Just as polygon CIG image generators are built in channels, each channel feeding a display window, so can Realscan be built in a similar way. Wide angle displays of multiple windows are equally feasible.

Particularly interesting are the possibilities for the Realscan concept in association with current display systems under development in which the pilot is presented with a display over a limited field of view in the direction in which he is looking, using head and eye tracking to control the image generator. Such a combination of image generator and display would give very high effective detail to the pilot for any position of his head and eyes.

Finally, the increasing use of infrared sensors must be mentioned. The simulation of an IR system requires a data base even more demanding for some systems, than visual simulation and the IR and visual data bases must possess the same correlated geometry as the radar data base. A Realscan type system may in the long run unify the simulation of all these sensors.

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# CONCEPTUAL DESIGN OF A ROTORCRAFT ADVANCED VISUAL SYSTEM*


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## ABSTRACT

A conceptual design is presented of a large field-of-view, high resolution visual system with an integrated flexible cab configuration that can be procured with a high degree of confidence in the 1982-84 time period. The mission requirements are defined for the Army Rotorcraft System Integration Simulator (RSIS) which incorporates this Advanced Cab and Visual System (ACAVS). A brief description is provided of the NASA-Ames Vertical Motion Simulator as it will be configured with ACAVS installed. Major ACAVS system requirements are addressed and some attention is given to their relationships to the intended mission. Four existing visual display technologies and computer generated imagery approaches are identified and their potential application to ACAVS is described. The ACAVS conceptual design is presented and a comparison is made of major requirements and goals to final system specifications.

The paper closes with a brief discussion of potential applications of the RSIS to future helicopter systems design, integration, product improvement evaluations and safety analysis.


## INTRODUCTION

Over the last 20 years, flight simulators have emerged as a recognized and widely accepted training tool. A survey of all 23 scheduled U.S. Airlines revealed that more than 70 modern flight simulators are owned and operated by the 18 airlines who replied to the survey. Currently, a very large part of all commercial airline flight training is conducted in those flight simulators[1].

The use of simulators for training within the Department of Defense (DOD) began during World War II to increase instrument flying proficiency. During the next twenty years, the feasibility of real time digital simulators for flight training was demonstrated. Weapons systems simulators followed with the development of the terrain model board and TV approach for visual simulation. In 1969 Apollo II landed on the moon validating, on the first flight, the effective use of total simulation in the training program[2].

While their value has been widely exploited by the fixed-wing industry for many years, piloted flight simulators have seen much less use by the rotary-wing industry. In 1971, the U.S. Army initiated an extensive program in the use of simulators for training helicopter aircrews with its introduction of the UH-1H Synthetic Flight Training System. Since then training simulators have been developed for the CH-47 Chinook and AH-1 Cobra, and one is undergoing acceptance testing for the UH-60A Blackhawk. Similarly, the U.S. Navy introduced a Weapons System Trainer for the SH-2F Seasprite in 1976 and have systems under development for the CH-46E Sea Knight and SH-3H Sea King[3].

In the fixed-wing aircraft industry the cost-effectiveness of piloted flight simulators has also been demonstrated in research and development[4]. It has become a primary tool in the understanding of the flight characteristics of new aircraft, the development of certification criteria, the validation of aircraft control concepts, and the formulation of new approaches to air traffic control procedures.

In contrast, there has been limited exploitation of man-in-the-loop simulation during the research and development phases of rotary-wing aircraft. Some examples are the use of Northrop's capabilities during development of the Heavy Lift Helicopter, simulations performed by Sikorsky and NASA-Langley in support of the tilt rotor development and Stability and Control Augmentation System (SCAS) failure investigations on the Bell 214.

In 1975, a joint U.S. Army and NASA study was performed to review the functions, status and future needs for ground-based flight simulation of rotary-wing aircraft. Contacts were made with the U.S. helicopter industry and with the various U.S. agencies concerned with the development of rotary-wing systems to assess the needs for research simulation. In the course of this review, the deficiencies in current simulation capability relative to rotary-wing aircraft requirements were defined with consideration of all the special aspects of this problem including mission, tasks, aircraft characteristics, environmental conditions, instrumentation and displays, performance and workload. Many of these aspects impose requirements quite different from those met by even the most sophisticated fixed-wing piloted simulators. As a result of this review[5], a program was initiated to develop a high-fidelity rotorcraft simulation capability that could be exploited by both government and industry in Research and Development (R&D). This simulation capability is being developed jointly by the Aeromechanics Laboratory and NASA at NASA-Ames Research Center, Moffett Field, California. The Aeromechanics Laboratory is one of four research laboratories assigned to the Research and Technology Laboratories (RTL) of the U.S. Army Aviation Research and Development Command (AVRADCOM).

### Research Simulator Requirements

There are many differences between fixed-wing aircraft and rotary-wing aircraft that imply different simulation requirements. Generally, fixed-wing aircraft fly high and relatively fast and are close to the ground only when landing or when taking off. In contrast, helicopters fly low and slow and, especially during military missions, are in close proximity to the ground during most of their flying time. The term Nap-of-the-Earth (NOE) (Figure 1) has been coined by the


**Figure 1. Terrain Flying Regimes**

*Much of the information presented in this paper was developed on NASA Contract NAS2-10464, NASA-Ames Research Center, Moffet Field, CA.

helicopter community to describe operations in which they fly only a few feet above the ground and fly around obstacles rather than over them. The environment for the pilots flying these missions is rich in detail – full of trees and bushes, hills, and valleys, which, while offering protection from the enemy, are lethal to an unwary pilot. Terrain features, visibility factors of weather and darkness, and atmospheric characteristics of wind, turbulence, and ground effect are all elements of the environment that may significantly affect the helicopter pilot's tasks. The helicopter crew must maneuver around and between obstacles and navigate, communicate, and proceed with the mission while maintaining awareness of threat weapons.

Fundamental differences in the environmental cues which have to be simulated for rotorcraft operations compared with fixed-wing aircraft result from these different flight conditions. The visual display is required to represent much more detail in the terrain and vegetation. Being close to the ground, terrain, and vegetation characteristics cause more complex atmospheric wind shear and turbulence characteristics. Slow flight speed and, in particular, the conditions in and around hover make assumptions of a non-time-varying turbulence model invalid, and satisfactory turbulence models more difficult to achieve. Slow flight and high maneuverability, especially of military helicopters, allow rapid changes of flight path to be achieved. This means that the field of view required for the pilot to see where he is going is wider than in a fixed-wing aircraft.

The basic control problems are more difficult too. In a fixed-wing aircraft with good handling qualities, the aircraft is stable, and control is largely a two-axis task with pitch and bank angles being used to direct the aircraft flight path. In a helicopter, especially at speeds approaching hover, pitch attitude becomes less effective in controlling flight path angles and more effective in controlling of speed, while an additional control, thrust, is required for rate of climb. In addition, heading is no longer controlled by bank angle but also requires an additional specific control through the yaw control. Thus, the pilot's control problem becomes much more complex; it now requires all four controls to be actively worked. In addition to this fundamental control problem, the basic helicopter is likely to be unstable and to have significant cross coupling between the various axes. All these complications associated with helicopters make the need for the additional cues provided by a simulator motion system greater than in the case of fixed-wing aircraft.

Finally, the mathematical model required for a reasonable representation of a helicopter must contain some elements of rotor dynamics, the extent depending on the purpose and nature of the simulation. Thus, the requirements on the visual, motion, and computational aspects are all different, and generally significantly more severe than those for a simulation of similar fidelity for a fixed-wing aircraft.

## Project Plan

The joint Army/NASA program to develop a high-fidelity R&D simulator, known as the Rotorcraft System Integration Simulator (RSIS), is now in its final phase. The first, or definition phase, started with the Army/NASA study in 1975[5], which led to additional studies to address the issues raised by the different requirements discussed previously for rotorcraft R&D simulation as opposed to fixed wing simulation. A feasibility study for helicopter/VTOL wide-angle simulator image generation displays system was completed by Northrop in 1977[6]. Results showed that wide field of view visual display (120°H x 60°V) was feasible using the techniques of image generation by camera model and image-presentation by three color projectors. The image presentation technique is still a possible candidate but the limited resolution and inability to expand the field of view suggest that Computer Generated Imagery (CGI) may be a better solution for image generation. Analysis of fixed-based simulations of NOE flight operations[7], has defined the cab excursions required for high fidelity simulation motion. Due to budgetary constraints and a desire to make maximum use of existing facilities, it was determined that the Vertical Motion Simulator (VMS) at NASA-Ames could be used, with modifications at the motion base for the RSIS. The VMS will be described in more detail later in this report. Two independent design studies to assess the possible modification were performed by Franklin Research Laboratory and Northrop Corporation in 1978[8][9]. Specifications were developed from these studies and a competitive RFP was issued to industry and the contract was awarded to Franklin Laboratory in 1979.

A new interchangeable rotorcraft cab, a development station, and an advanced visual system, known as the Advanced Cab and Visual Systems (ACAVS) will complete the RSIS project. The development station and interchangeable rotorcraft cab will enable Army/NASA researchers to release the VMS for additional experiments while reconfiguring the cab in the development station for the next rotorcraft experiment. The advanced visual system will be a wide field of view system with look-down capability. An overview of the RSIS project and its relationship with the VMS is shown in Figure 2. The final configuration with all component parts is also shown, conceptually, in Figure 3. The dome concept is shown as a feasible concept only and does not imply that other concepts will not be considered for the advanced visual system.

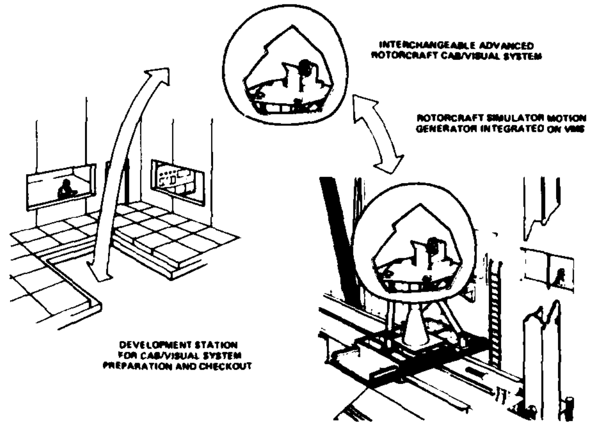


**Figure 2. The Vertical Motion Simulator (VMS) RSIS Project Overview**

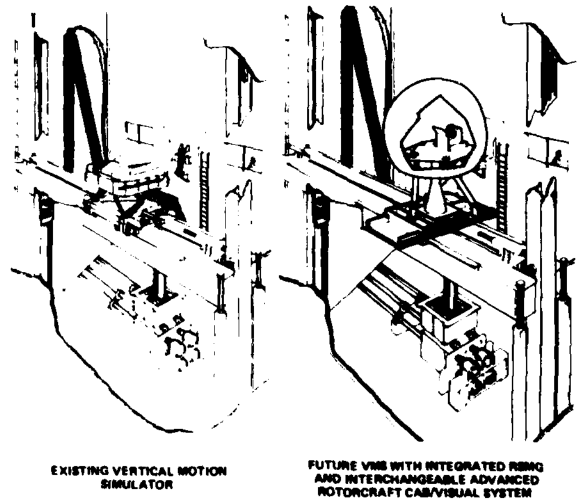


**Figure 3. Final RSIS System**

To provide an effective review of rapidly advancing technology, especially in the visual area, a preliminary design study contract was awarded to Boeing Military Airplane Company in late 1979. Their finding will be discussed next. A Statement of Work and RFP was developed from their study and is awaiting release to industry. The ACAVS contract will be awarded in 1981 and the RSIS is scheduled to become operational in 1985.

## VERTICAL MOTION SIMULATOR DESCRIPTION

The Vertical Motion Simulator (VMS) is a large man-carrying simulator now in operation at Ames Research Center. The VMS consists of a hydraulic motion system mounted on a structure with large lateral and vertical motion capabilities. Vertical motion is the primary degree-of-freedom and all other modes are built on top of it. A long horizontal platform is supported by two vertical columns. Currently eight (8) DC servo-motors drive the simulator sixty feet vertically through gear reducers, pinions, and racks which are attached to the columns. Lateral motion capability of forty feet is provided by a carriage which is driven across the vertical motion platform. Four (4) DC servo-motors drive through reducers and pinions to engage a fixed rack on the vertical motion platform.

As a part of the RSIS program the hydraulic motion system presently mounted on the vertical and lateral structure is being replaced with the Rotorcraft System Motion Generator (RSMG). The overall performance envelope of the combined device is projected to be as follows:

| Mode | Displacement | Velocity | Acceleration |
|---|---|---|---|
| Vertical (Z) | ± 30 ft. | ± 20 ft/sec | ± 32.2 ft/sec$^2$ |
| Lateral (Y) | ± 20 ft. | ± 10 ft/sec | ± 24 ft/sec$^2$ |
| Longitudinal (X) | ± 4 ft. | ± 4 ft/sec | ± 10 ft/sec$^2$ |
| Roll | ± 78° | ± 40°/sec | ± 115°/sec$^2$ |
| Pitch | ± 18° | ± 40°/sec | ± 115°/sec$^2$ |
| Yaw | ± 24° | ± 46°/sec | ± 115°/sec$^2$ |

These peak motion system requirements are defined for a maximum growth payload that includes all hardware attached to the motion system with the following characteristics:

| | | |
|---|---|---|
| Weight | = | 8,000 lbs |
| Ix-x | = | 26,000 in-lb-sec$^2$ |
| Iy-y | = | 31,000 in-lb-sec$^2$ |
| Iz-z | = | 31,000 in-lb-sec$^2$ |

## ADVANCED VISUAL SYSTEM REQUIREMENTS

The prime projected use of RSIS is handling qualities investigations. In rotorcraft systems, handling qualities depend heavily upon the outside visual scene for most missions. Requirements for ACAVS visual systems stem from the following NASA user-defined simulator mission tasks.

- Nap-of-The-Earth Terrain Flight
- Night Operations
- Instrument Flight
- Sling-Load Control
- Conventional Day VFR
- Air Combat

These tasks require a visual system with a uniquely wide range of performance. The most stringent requirements flow primarily from the NOE mission with its out-the-window visual scene incorporating near and far field objects that are viewable over a significant percentage of full field. These objects represent scenes that are rich in detail. This places a heavy requirement on image generation capability particularly when realism is needed for pilot acceptance.[10] For the purposes of ACAVS preliminary design and development, it has been found that visual display and CGI technologies have in common only a small number of well defined interactions. Primary emphasis in this paper is placed on the display concept as the visual system design driver.

For clarity, the specific requirements associated with visual display systems and those associated with image generation will be discussed separately.

### Display Systems Requirements

Specific display performance requirements that were used in the ACAVS display system preliminary design are shown in Table 1.

**Table 1. ACAVS Display Performance Requirements**

| Parameter | Minimum | Goal |
|---|---|---|
| Field of View | 120°H x 60°V* | 240°H x 180°V |
| Image Resolution | 6 arc Min.** | 3 arc Min.** |
| Brightness | .03 - 30 fL | .03 - 50 fL |
| Color | 2 Color | Full Color |
| Contrast Ratio | .03 - 30 | -- |
| Slew Rate | 60°/Sec | 100°/Sec |

*Instantaneous FOV, rotatable as a goal
**Measured in optical line pairs as seen at the display

Visual parameters most critical in ACAVS display system design are Field of View (FOV) and image resolution. A typical view polar of a large side-by-side rotorcraft that illustrates the demanding FOV requirements is shown in Figure 4. Other parameters of importance in the overall display system design are image brightness, color, contrast ratio, slew rate and distortion. A full discussion of the origin of these performance parameters is not within the scope of this paper.

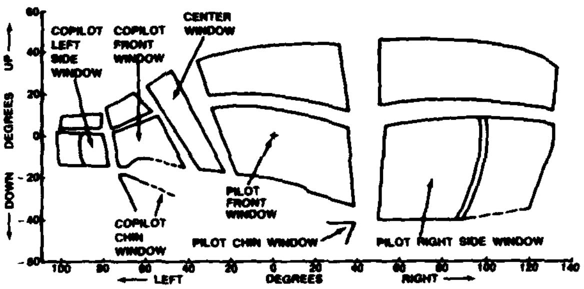


**Figure 4. CH-46 Cockpit FOV from Pilot's Design Eyepoint [11]**

The FOV requirements include a 60° downlook potential forward and to the side. A sketch of the percentage of full field view is shown in Figure 5 for both the minimum requirement and the desired goal.

Resolution requirements are driven by the need to provide precise control of linear velocity that must occur near the terrain and to perform target tracking tasks that may include acquisition of targets at realistic distances. For reference, it has been shown that detection of a tank at 2000 meters requires a resolution of about three arc minutes per line pair[12]. Peripheral vision requires somewhat less resolution since the relative acuity of the eye drops to about 10% at 40° from the center of the fovea.

### Visual Image Generation

Visual image generation is an important and complex part of visual system concept design. Even though the major thrust in this paper is directed toward display concepts, the discussion that follows offers an abbreviated overview of some major image generation design considerations.

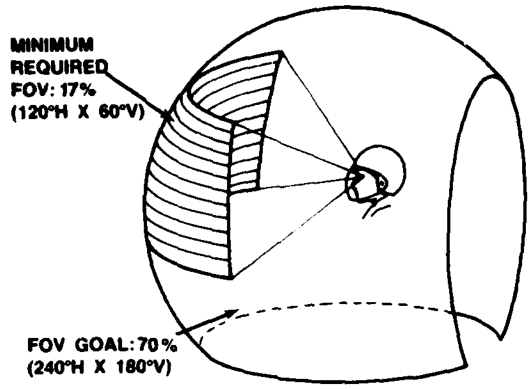


**Figure 5. ACAVS Percentage of Full Field Vision**

Visual Image Generation

There are many factors that influence image generation design. These include:

| | |
|---|---|
| Field of view (FOV) | Image resolution |
| Scene detail | Level of detail control |
| Number of displayable edges | Moving models |
| Curved surface shading | Weapon effects |
| Color | Texturing |
| Frame rate | Atmospheric effects |
| Transport delay | Gaming area |

Three of these factors have major impact on the design: Field of view, image resolution and scene detail. As in display system design, the product of field of view and image resolution is a basic performance measurement and relates directly to the number of pixels that must be computed in computer generated image systems (CGI). Scene detail is difficult to specify in such a manner that only those requirements are placed upon the CGI design that are directly related to the ACAVS mission task. This is an important consideration since it is generally accepted that any attempt to produce individual detail equivalent to the level perceivable by the human eye would be futile with present technology. However, texturing methods and memory intensive algorithms being developed show much promise.

TECHNOLOGY ASSESSMENT

A technical assessment of systems that will be viable for ACAVS in the 1982-84 time period indicates advancement of several visual system components. An assessment of six of these that show particular promise is given here:

1) Television projectors are nearing production that use liquid crystal displays with significantly lower scene lag by a factor of at least two compared with those previously available.

2) Scanning laser systems offer high resolution images over a larger field-of-view per projector than any other display system surveyed.

3) In-line virtual image windows are being made lighter weight and more light efficient by substitution of holographic elements for the heavy optical lenses.

4) Studies are available that show potential of expanding the field-of-view of large exit pupil virtual imagery systems to 70°V x 100°H.

5) High resolution fiber optics are being used to supply images for helmet mounted virtual image displays or for real image projection on large spherical screens.

6) An optical extension lens display technique is also available that will lower distortion caused by off-center projection spherical screen systems.

Further description of several of these display system components is provided in the discussion of various system concepts.

Image Resolution Factor

A factor basic to the information presentation ability for wide angle displays generation is related to the ratio of field-of-view and image resolution. Because of the interdependence of these parameters their product may be used and form a figure of merit which can serve as a comparison between potential ACAVS presentation sources (e.g., television projectors and scanning lasers). These parameters can normally be traded against each other in any specific system design. A comparison of several existing projection system capabilities is shown in Figure 6. It is noted that the scanning laser has an Image Resolution Factor significantly above the rest. However, if a third factor related to delivered brightness is considered, the light valve systems rate more favorably relative to the laser systems. For the purpose of this paper, image resolution is defined conservatively such that an interlaced television raster display consisting of 1000 viewable lines subtending a total vertical angle of 36 degrees to the eye is said to have 6 arc minutes of resolution per line pair (assuming a Kell factor of .71).

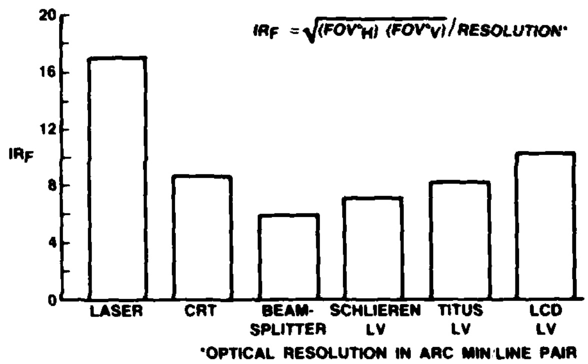


**Figure 6. Projector Image Resolution Factor**

ADVANCED DISPLAY SYSTEM CONCEPTS

Four feasible display system concepts can be postulated that incorporate one or more of the technology advancements assessed above. The order in which these concepts are discussed below is unrelated to their preference as potential RSIS simulator designs. The first three concepts discussed utilize a spherical screen the external dimension of which is limited to 20.5 ft in order to clear the walls of the VMS facility under all rotational and translational excursions. The performance characteristics given are for selected display projectors only. Any of the projector types evaluated in Figure 6 are potentially usable although system efficiency may limit use of those with lower light output. All slewable display scenes will project 60 degrees downward.

Light Valve and Extension Optics Concept

This relatively conventional configuration uses three light valve projectors combined with extension optics. The concept is depicted in Figure 7. The extended "periscope" design of the optics allows the placement of lenses near the center of a spherical screen to minimize distortion, channel matching and focus problems. A head tracker on the crew member's helmet controls the motion of the projector and optics in the pitch axis. Projector images are edge matched by masking inside the extension optics. Advantages of this concept are low design risk and high scene brightness. Disadvantages are lateral FOV limitations and resolution marginality.

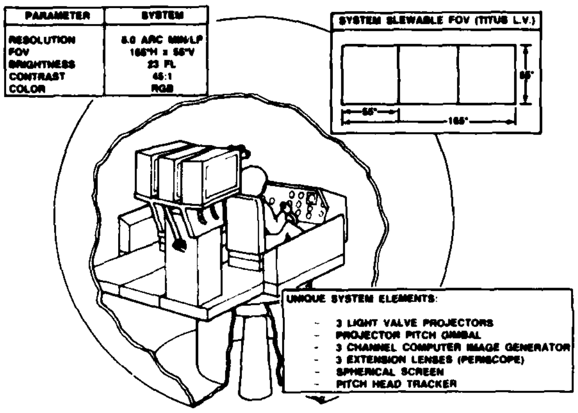


**Figure 7. Light Valve and Extension Optic Visual System Concept**

Light Valve and Fiber Optics Concept

In this concept flexible coherent fiber optic bundles transmit images to an optical head from three light valve projectors fixed to the crew station platform. The fiber optic bundles are frequency multiplexed to minimize the effect of individual fiber breakage. The optical head is gimbaled as shown in Figure 8. The gimbal is slaved to the motion of the crew members helmet in pitch and yaw and rotates about the exit pupil of the optics. The image is a composite designed with high resolution in the central area of the display by insetting one of the channels of 6.5 arc min/Lp resolution in a pair of lower resolution fields. Advantages of this approach include reduced gimbal drive power requirements and wider total field of view than the preceding concept.

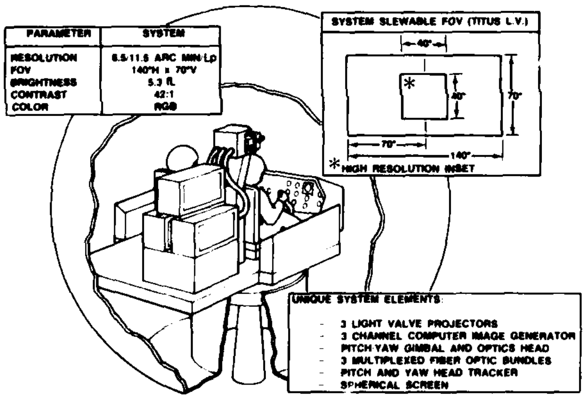


**Figure 8. Light Valve and Fiber Optics Visual System Concept**

A second approach (not shown) using the same light valve projectors and fiber optics eliminates the gimbal and adds a fourth channel to widen the instantaneous field of view. With this arrangement a 223-degree horizontal field of view with composite resolution fields is feasible at a brightness reduction to about 2.3 fL. This approach increases the reliability and instantaneous field of view but decreases the resolution on the sides to a marginal 13 arc minutes. There is also an undesirable 47-degree long horizontal "window" joint at the center of the display scene.

Scanning Laser Concept

The use of a scanning laser allows the projection of a bright collimated beam of light on a spherical screen with a vertical raster scan. As in the previous concepts, the scanner projector is positioned above the crew member's heads as shown in Figure 9. Because of the large depth of field the projector is not constrained to the screen center. The display is slewable in pitch and is slaved to helmet position in pitch.

Advantages of the laser concept are good resolution and wide instantaneous field of view. The large continuous scan requires special interface considerations with computer image generation hardware.

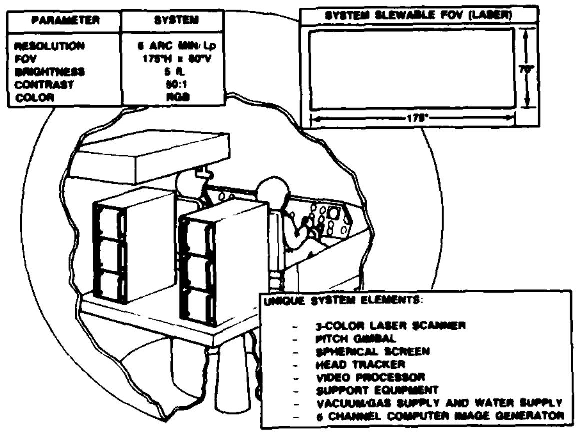


**Figure 9. Scanning Laser Visual System Concept**

Helmet Mounted Display Concept

In this concept a small virtual imaging system is mounted on a crew members helmet. Three light valve projectors relay the visual images to this Helmet Mounted Display (HMD) via flexible coherent fiber optic bundles. The three images are processed optically into two scenes, one for each eye, at the output of the projectors. The sketch in Figure 10 depicts a concept using two such systems.

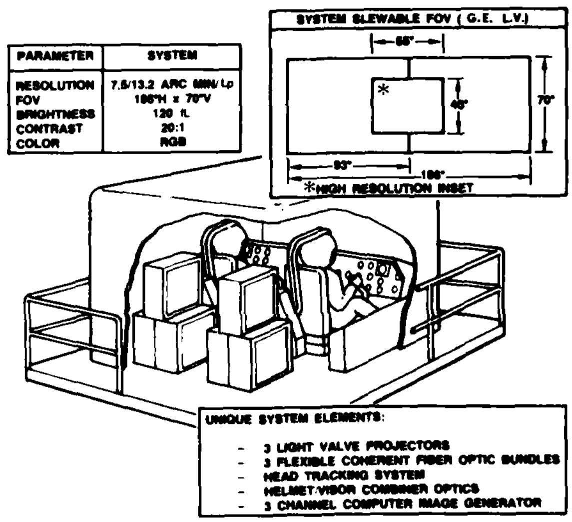


**Figure 10. Helmet-Mounted Display Visual System Concept**

The HMD has optical combiner lenses which permit "viewing" of the internal cab and instruments in the areas of view where the CGI image is blanked. Prior cockpit mapping provides cab interior polar pilot information to blank the image. An artist's concept of this HMD blanking is shown in Figure 11. A head tracking system provides pilot head position information to the CGI visual system.

The advantages of the HMD approach are numerous. The concept offers effectively unlimited total field of view with a minimum of distortion. Illumination efficiency is adequate to allow a wide range of projector possibilities. Elimination of external screen or other optical elements allows a large space and weight saving. Disadvantages include some head encumberance and some incompatibility with actual aircraft helmet mounted hardware. However of all the concepts studied, the HMD uses the newest and least proven techniques and thus involves the highest risk.

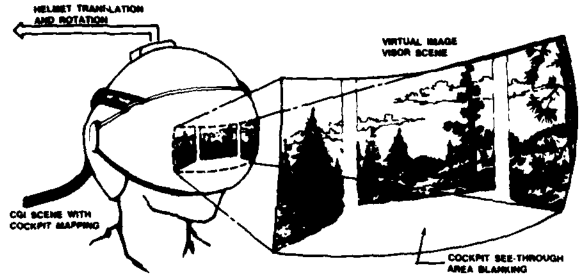


**Figure 11. Helmet-Mounted Visor Display Blanking**

## VISUAL SYSTEM CONCEPTS EVALUATION

Although no single system concept (display concept and image generator) will completely meet all the requirements set forth by the RSIS program, any one of the approaches will provide a substantial portion. There is no imminent technology break-through that will exceed the ACAVS system requirements. Rapid progress is however, being made in the areas of helmet mounted displays, scanned laser systems and computer generated imagery. Some areas such as HMD will need to be addressed in further detail before a design decision is made to implement them in a system design.

Although proposed as a research and development device, ACAVS advanced visual system concepts employ many features that would seem to be valuable for many future flight trainers and especially, of course, rotorcraft flight trainers. Their wide fields of view coupled with high resolution allow a wide latitude for designers seeking to fulfill difficult training requirements associated with visual target acquisition and tracking, weapons delivery and landing as well as NOE flying techniques.

## EXPECTED BENEFITS

The Army/NASA, 1975 study[4], concluded that the utilization of a helicopter R&D simulator fell into two categories:

a. Support of basic technology: This work consists of generalized or generic studies of stability and control, handling qualities, controls and displays, and other aspects of the man-machine interface.

b. Support of the development of new aviation systems or improvements to fielded systems: These efforts start early in an aircraft acquisition cycle by assisting the User and the Developer in performing design studies and system integration evaluations and trade-offs.

During recent years a coordinated program has been undertaken at Ames Research Center to provide a data base for helicopter handling qualities and control system design criteria. As indicated in Figure 12, advancements in rotor systems and their associated flight controls offer the most direct method of improving flying qualities and reducing pilot workload in the NOE regimes (Figure 1) where Army helicopters operate. Chen and Talbot[13], investigated four major rotor system design parameters to assess the handling qualities for 44 configurations of main-rotor systems which cover teetering, articulated and hingeless families of rotor systems with a wide range of blade inertia. They concluded that within each family of rotor systems, satisfactory handling qualities were obtained by appropriately adjusting the rotor parameters. No rotor system was

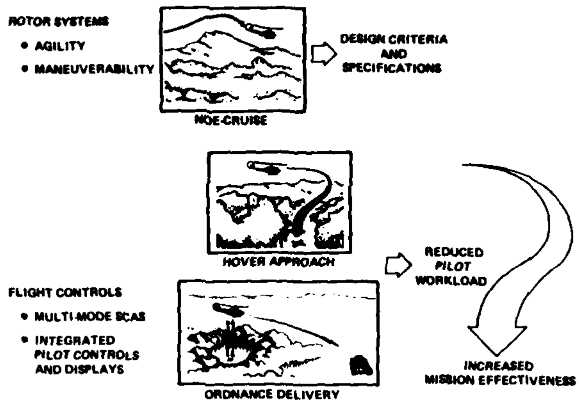


**Figure 12. Helicopter Handling Qualities Research**

uniformly superior in NOE handling qualities. It follows that additional experiments will be required to optimize the handling qualities for specific missions conducted in the NOE environment.

Aiken and Merrill[14] investigated control system variations for an attack helicopter mission. This was part of a major area of research aimed at reducing pilot workload of highly maneuverable helicopters that are intended to function as stable platforms for target designation or weapon delivery at night or under adverse weather conditions. Two candidate techniques are under investigation: (1) modifications to the control system, and consequently the handling qualities, as a result of different flight modes; e.g. – cruise, approach to a hover, hover, bob-up, pop-up, etc; and (2) variations in the method by which critical information is displayed to the pilot. Both of these techniques have great potential for reducing pilot workload and additional experiments are planned.

The uses of R&D simulators in the development of new aviation systems or improvements to fielded systems follow the life cycle of system development. During the program initiation phase, the simulator can be used to evaluate new aviation design concepts that have been developed by the U.S. Army Training and Doctrine Command (TRADOC), to meet a specific threat. This evaluation can help answer the questions and support the rationale leading to a Mission Element Needs Statement (MENS). After the MENS is approved, the R&D simulator can be used in the demonstration and validation phase for evaluating the flying qualities of competing designs as well as the ease of future systems integration efforts.

Finally, the simulator can be used for engineering development and product improvement. As the design evolves, either on paper or as a result of initial flight testing, changes to correct shortcomings in either flying qualities or total performance can be evaluated for their effectiveness as well as their undesirable side-effects. Project managers can also use the simulator to evaluate product improvement proposals prior to actual hardware fabrication and expensive flight qualification.

Flight simulation is an important tool in helicopter research and development, both for technology base development and for aircraft development programs. The RSIS will be a unique capability for use by both government and industry in an effort to maintain our current lead in helicopter development and production in the free world.

## ACKNOWLEDGEMENT

The authors would like to acknowledge the efforts of R. L. Starr, Boeing Military Airplane Company, in the preparation of this paper.

Addendum: Funding of certain research and development projects involving liquid crystal display and holographic lense elements technologies has been withdrawn. This will, in all probability, jeopardize the availability of these technologies for the RSIS Program.

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# COST-EFFECTIVENESS OF COMPUTER-BASED INSTRUCTION FOR MILITARY TRAINING

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## ABSTRACT

The cost and effectiveness of computer-based instruction for military training are evaluated on the basis of about 30 studies conducted since 1968. Four methods of instruction are distinguished and compared: Conventional Instruction, Individualized Instruction, Computer-Assisted Instruction (CAI) and Computer-Managed Instruction (CMI). Student achievement at school is about the same with all methods of instruction. CAI and CMI save about 30 percent (median) of the time required by students to complete the same course given by conventional instruction. Individualized instruction (without computer support) also saves student time; the addition of CAI or CMI to courses taught this way saves little additional student time. Student attrition appears to increase with CMI compared with conventional instruction, but changes in student quality may also account for this increase; no such data are available on CAI. Students prefer CAI or CMI to conventional instruction; attitudes of instructors, considered in only a few studies, are unfavorable to CAI and CMI. Direct comparisons of the cost and effectiveness of different methods of instruction are not now possible because of incomplete cost data. Most so-called cost savings attributed to CAI and CMI are based on estimates of pay and allowances of students for the time saved by these methods of instruction; data for other costs, such as for CAI or CMI equipment, courseware and instructors must also be considered.

## INTRODUCTION

The training of military personnel is a large and continuing activity for the military Services. This paper evaluates the cost and effectiveness of modern training methods which use computers to instruct students and to manage students' progress through a course. (1)

In Fiscal Year 1981, about 428,000 enlisted personnel will receive initial skill training, 173,000 will receive skill progression training and 515,000 will receive functional training at a cost of over $2 billion. (2) About 70 percent of all recruits complete their initial enlistment; less than 40 percent reenlist for a second term; thus about 75 percent of the training loads and costs noted above are related to new accessions each year. (2)

After graduating from technical training schools, personnel are assigned to operational commands where they receive additional on-the-job training, crew, team and unit training and practice in field exercises. These types of training have large costs which must be added to the costs cited above.

Industry is well aware of the need to reduce the costs of military training and some type of computer-based instruction is often incorporated now in new proposed systems such as, for example, the new aircraft training system (Navy VTXTS) and maintenance simulators (F-16). This paper evaluates what is now known about the cost and effectiveness of various types of computer-based instructional systems.

## METHODS OF INSTRUCTION

Carpenter-Huffman lists 20 different methods of instruction in "Method of Designing Instructional Alternatives" (MODIA) (3); these include lectures, discussions, tutoring, independent study, drill and practice. For convenience, we have organized these methods of instruction into four groups; more than one method of instruction may be used in a course.

Conventional Instruction. Conventional instruction refers to many possible combinations of lectures, discussions, laboratory exercises and tutorial sessions. A key feature of conventional instruction is that groups of students proceed through a course at the same pace. Differences in the amount of information retained by students are reflected in their grades at the end of the course. Conventional instruction is also referred to as lock-step instruction and group scheduling. It is used in 75 to 90 percent of all military courses, although a precise estimate is not available.

Individualized Instruction. In individualized instruction, a course is arranged in a series of lessons through which each student proceeds at his own pace. Mastery of each lesson is required as a condition of progress and there is a test for each lesson. Differences among students are reflected in the amount of time it takes them to complete a course, although grades may also be given.

Various versions of individualized instruction may differ in such ways as the amount of new material between lessons, the order in which lessons are provided to the student (main line, branching) and the extent to which the student is completely free to proceed at his own pace. All methods of computer-based instruction rely on some form of individualized instruction; the term "individualized instruction", as used here, is meant to apply only to individualized instruction conducted *without* computer support. The terms individualized instruction, self-pacing, and programmed instruction are often used synonymously.

Computer-Assisted Instruction (CAI). The term computer-based instruction, as used here, includes both CAI and CMI. In computer-assisted instruction (CAI), the student interacts in real time, via an interactive terminal, with instructional material that is stored in the computer. This offers great flexibility for presenting alternative versions of the same lessons according to each student's particular ability and way of learning. Most CAI systems diagnose student performance, prescribe lessons, and maintain student records. Examples of some CAI systems follow:

- PLATO: Programmed Logic for Automatic Teaching Operation. The current version of this system, PLATO IV, can support about 950 terminals linked through microwave and land-line communications to a large central computer (CDC CYBER 74) located at the University of Illinois.

- TICCIT: *Time-Shared Interactive Computer-Controlled Information-Television.* The basic TICCIT system uses one or two mini-computers to support up to 128 terminals at one location.

- LTS: Lincoln Terminal System. The latest version, LTS-5, uses microfiche to store both visual images and an audio track. This is a self-contained or "stand-alone" system.

- GETS: General Electric Training System. This is a stand-alone system which uses a random access 35-mm slide projector for visual displays and floppy discs for lessons and playback.

Computer-Managed Instruction (CMI). In computer-managed instruction (CMI), instruction takes place away from the computer. After each lesson, the student takes a test, and places the answer sheet on an optical scanner; the computer scores the test and interprets the results. The student receives the results on a printout which tells him how well he performed, what lesson to take next, and where to find it. The computer also manages student records, instructional resources, and administrative data. Examples of some CMI systems follow:

- AIS: Advanced Instructional System. This prototype system is installed at the Air Force Technical Training Center, Lowry Air Force Base, Denver, Colorado. It contains 50 student terminals, 11 management terminals, and a CDC CYBER 73-16 computer which can support up to 3,000 students a day in four courses. These courses were selected to represent a cross section of the technical training courses at Lowry AFB and account for about 25 percent of the student body. The management terminals are used by instructors for developing or revising lessons and for retrieving data collected by the system. The system could be expanded to provide CAI services to students.

- Navy CMI: Computer Managed Instruction System. This system, installed at Naval Air Technical Training Center, Millington, Tennessee, handles about 6,000 students in 11 schools at 5 training centers. It is based on a Honeywell Series 60, level 66 computer.

- CTS: Computerized Training System. This system, installed at U.S. Army Signal Center and School, Fort Gordon, Georgia, can provide CAI and CMI services for 128 terminals. It is based on six mini-computers (PDP-11/35s). Each terminal contains a visual display unit and a keyboard which can provide both interactive instruction and course management services.

## DISTINCTIONS BETWEEN MILITARY AND NON-MILITARY TRAINING

Military personnel receive pay and allowances while they are being trained. Thus, any procedure which can reduce the length of time required for training, without significantly affecting the amount and/or quality of information acquired, can help to reduce the cost of training; it can also help to increase the amount of time spent by military personnel in operational assignments during their military careers. Military training courses are designed to qualify students for well-defined jobs to which they can be assigned upon successful completion of these courses.

This situation differs from that found in almost all types of public and private schools where students are not paid and must remain at school for required periods of time. These schools receive no direct benefit if students complete their instruction in less than the required time. Courses are generally not designed to qualify students for particular jobs and, obviously, schools cannot assign students to jobs when they graduate.

A major consequence of these distinctions is that methods of instruction that are cost-effective for military training may not be cost-effective in other applications. Another is that research on computer-based instruction supported by the military Services has emphasized the possibility of saving student time while maintaining student achievement constant. Research on instruction in non-military settings has emphasized student achievement at school and has not been concerned with the amount of time needed by students to acquire course materials.

## THE EFFECTIVENESS OF COMPUTER-BASED INSTRUCTION

The military Services have supported research and development on computer-based instruction since the early 1960's when this concept first appeared to be feasible. The use of CAI and CMI in military training has been evaluated in about 30 studies conducted since about 1968; these studies provide 48 sets of data. Most of these studies were of a research nature and only a few approximated an operational application. The nature of these studies must be understood in order to interpret properly the data they provide.

Military training is intended to prepare personnel to perform various jobs in operational commands. Thus, the effectiveness of any method of instruction should be evaluated by measuring how well a course graduate performs certain jobs in the field. No studies provide this type of information. Instead, all studies of different methods of instruction compare only student achievement at school, as measured by tests administered there. This limitation applies generally to most research on training and selection.

Most studies were, in fact, experiments. About half involved 50 or fewer students; about half the courses studied lasted one week or less. In a few studies, the courses lasted 2 to 10 months and involved 600 to 2000 students. This information is summarized in Fig. 1. A wide variety of subject matter was considered in these courses (see Fig. 2);

| No. of Students (CAI/CMI only) | Average length of conventional course: up to | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Not Stated | 1 Day | 1 Week | 1 Month | 2 Months | 3 Months | 4 Months | >4 Months | Total CAI | Total CMI |
| Not stated | | | 1 | | | | | | 1 | |
| 1 - 9 | | 1 | 1 | | | | | | 2 | |
| 10 - 49 | 2 | 9 | 5 | | 5 | | | | 21 | |
| 50 - 99 | | 3 | 5 | 2/2 | | | | | 10 | 2 |
| 100 - 199 | | | 1 | 2/2 | 1 | | | | 4 | 2 |
| 200 - 299 | | | 1 | | | | | | 1 | |
| 300 - 399 | | 1 | | | | | | | 1 | |
| 600 - 699 | | | | | | 0/1 | | 0/1 | | 2 |
| 2000 - 2999 | | | | | | 0/1 | | 0/1 | | 2 |
| Total CAI | 2 | 14 | 14 | 4 | 6 | | | | 40 | |
| CMI | | | | 4 | | 2 | | 2 | | 8 |

**NOTE: All entries in table refer to CAI except where two values are shown. Then, read "CAI/CMI".**

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FIGURE 1. Distributions of Course Length and Number of Students in 48 Evaluations of Military CAI and CMI Instruction

| Courses | No. of Evaluations CAI | No. of Evaluations CMI |
|---|---|---|
| Basic electronics | 15 | |
| Electricity | 5 | |
| Machinist | 2 | |
| Training materials development | 1 | |
| Recipe conversion | 2 | |
| Aircraft panel operation | 1 | |
| Medical assistant | 4 | |
| Vehicle repair | 4 | |
| Weather | 1 | |
| Tactical coordinator (S-3A) | 1 | |
| Fire control technician | 4 | |
| Aviation familiarization | | 2 |
| Aviation mechanical fundamentals | | 2 |
| Inventory management | | 1 |
| Materiel facilities | | 1 |
| Precision measuring equipment | | 1 |
| Weapons mechanic | | 1 |
| Total | 40 | 8 |

12-29-78-8

FIGURE 2. Courses Used in Various Studies of CAI and CMI

many of them are directly related to technical training, e.g., basic electronics and electricity; some involved hands-on maintenance checkout and repair. Note, however, that no single course was given both by CAI and CMI; as a result, this means that we cannot directly compare the effectiveness of CAI and CMI for giving the same course.

Student Achievement at School. Student achievement at school with CAI was about the same as with conventional instruction in 24 cases, superior in 15, and inferior in one (Fig. 3). The differences in achievement, although statistically significant, were not judged to have practical significance. Student achievement at school with CMI was about the same as with conventional instruction (8 cases).

Amount of Student Time Saved. Data on the amount of student time saved by CAI and CMI, compared to conventional instruction, are shown in Fig. 4. The amounts saved range from -31 to 89 percent; most values are positive; the median value is about 30 percent. No particular significance can be attributed to differential time savings between CAI and CMI shown in these data because direct comparisons, using the same courses, were not made. A major uncontrolled variable in these studies is the unknown quality of the instructional materials used in the various comparisons. This argues against trying to make quantitative comparisons about the amount of student time saved by different types of CAI or CMI, or in different courses, and so on.

The fact that CAI and CMI save student training time is consistent with the well-known fact that there are wide differences in student ability (represented by the normal distribution curve); there are also differences between students in the amount of relevant knowledge held by them at the start of any course. In conventional instruction

| METHOD OF INSTRUCTION | SYSTEM | SERVICE | LOCATION | STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction) INFERIOR | SAME | SUPERIOR | TYPE OF TRAINING |
|---|---|---|---|---|---|---|---|
| CAI | IBM 1500 | A | SIGNAL C&S | | • • • • | • • | ELECTRONICS |
| | | N | SAN DIEGO | | | • • • • • | ELECTRICITY |
| | PLATO IV | A | ABERDEEN | | • • • | | MACHINIST |
| | | N | SAN DIEGO | | • • | • • • • | ELECTRONICS |
| | | N | SAN DIEGO | | • • | | RECIPE CONVERSION |
| | | N | NORTH ISLAND | | | • | A/C PANEL OPERATOR |
| | | AF | SHEPPARD | | • • | • • | MEDICAL ASSISTANT |
| | | AF | CHANUTE | | • • • • | | VEHICLE REPAIR |
| | LTS-3 | AF | KEESLER | | • • | • | ELECTRONICS |
| | | AF | KEESLER | | • | | WEATHER |
| | TICCIT | N | NORTH ISLAND | | • | | TACTICAL CO-ORD. (S-3A) |
| | IDIOM | N | DAM NECK | • | • | | FIRE CONTROL TECHNICIAN |
| | PLATO IV | N | DAM NECK | | • • | | FIRE CONTROL TECHNICIAN |
| | | | | TOTAL 1 | 24 | 15 | |
| CMI | NAVY CMI | N | MEMPHIS | | • • | | AVIATION FAMILIARIZATION |
| | | N | MEMPHIS | | • • | | AV. MECH. FUNDAMENTALS |
| | AIS | AF | LOWRY | | • | | INVENTORY MGMT. |
| | | AF | LOWRY | | • | | MATERIEL FACILITIES |
| | | AF | LOWRY | | • | | PREC. MEASURING EQPT. |
| | | AF | LOWRY | | • | | WEAPONS MECHANIC |
| | | | | TOTAL 0 | 8 | 0 | |

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FIGURE 3. Student Achievement at School for CAI and CMI, Compared to Conventional Instruction, in Military Training

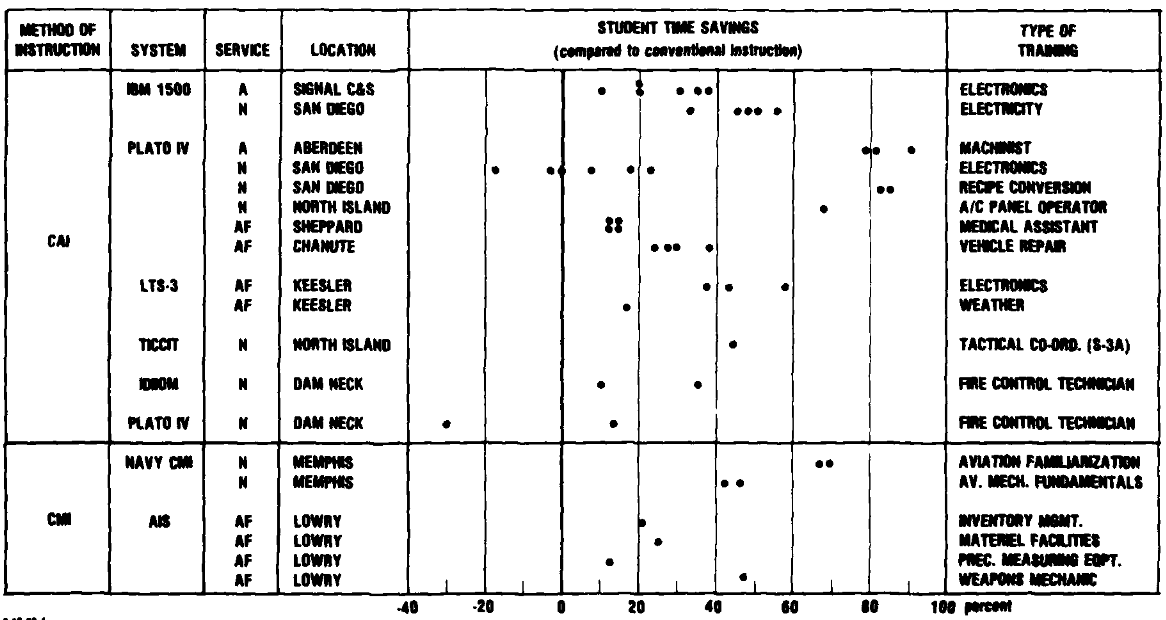


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FIGURE 4. Amount of Student Time Saved in Courses Given by CAI and CMI, Compared to Conventional Instruction, in Military Training

with a fixed amount of time, these differences lead to variations in the amount of knowledge held by students at the end of the course, i.e., as shown by a distribution of final grades. In individualized instruction, whether computer-based or not, each student proceeds at his own pace and differences between students influence the amount of time needed to acquire the course materials. Differences in the amount of information acquired is not a major variable. The bulk of the time savings in individualized instruction is produced by those students for whom the rate of progress set in conventional instruction would be too slow; typically that rate might be one that permits about 90 percent of the students to complete the course during the fixed period of time. Figure 5 summarizes the amounts of student time saved shown above.

| Method of Instruction | Number of Comparisons | Student time savings, compared to conventional instruction, percent | |
|---|---|---|---|
| | | Median | Range |
| CAI | 40 | 29 | -31 to 89 |
| CMI | 8 | 44 | 12 to 69 |
| Combined | 48 | 32 | -31 to 89 |

12 29 78-18 4-18 79

FIGURE 5. Amounts of Student Training Time Saved by CAI and CMI, Compared to Conventional Instruction

Course Completion Times at AIS over 24 Months. Almost all of the data shown previously represent time savings found in experiments or operational applications over short time periods and with limited numbers of students. Figure 6 shows time saved by about 11,000 students in four courses on the Air Force Advanced Instructional System (AIS), Lowry AFB for 24 months ending September 1978. It is clear that the initial savings, such as might be reported in an experiment, are maintained over time and, despite monthly fluctuations, tend to increase. These reductions are probably due to periodic revisions in the courses (indicated on the figure) and to improved control over the new method of instruction; fluctuations are probably due, at least in part, to variations in student aptitude and to other factors that are presently unknown.

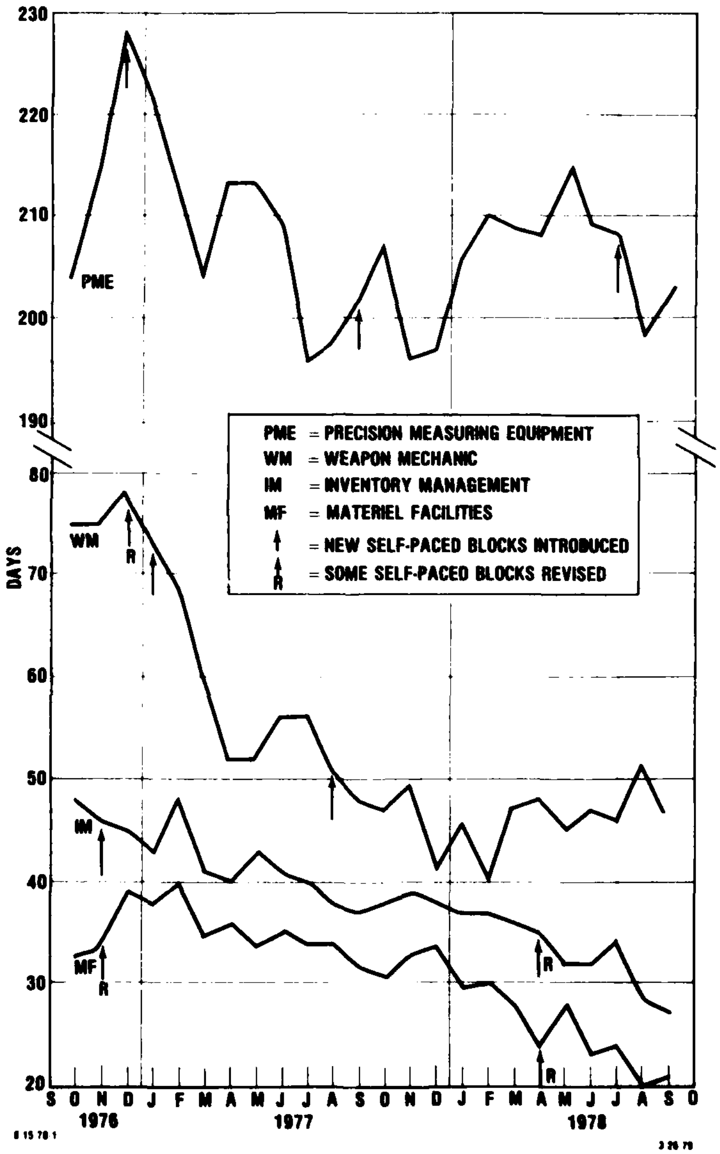


FIGURE 6. Days Required to Complete Four Courses on Air Force Advanced Instructional System, Lowry AFB, October 1976 - September 1978

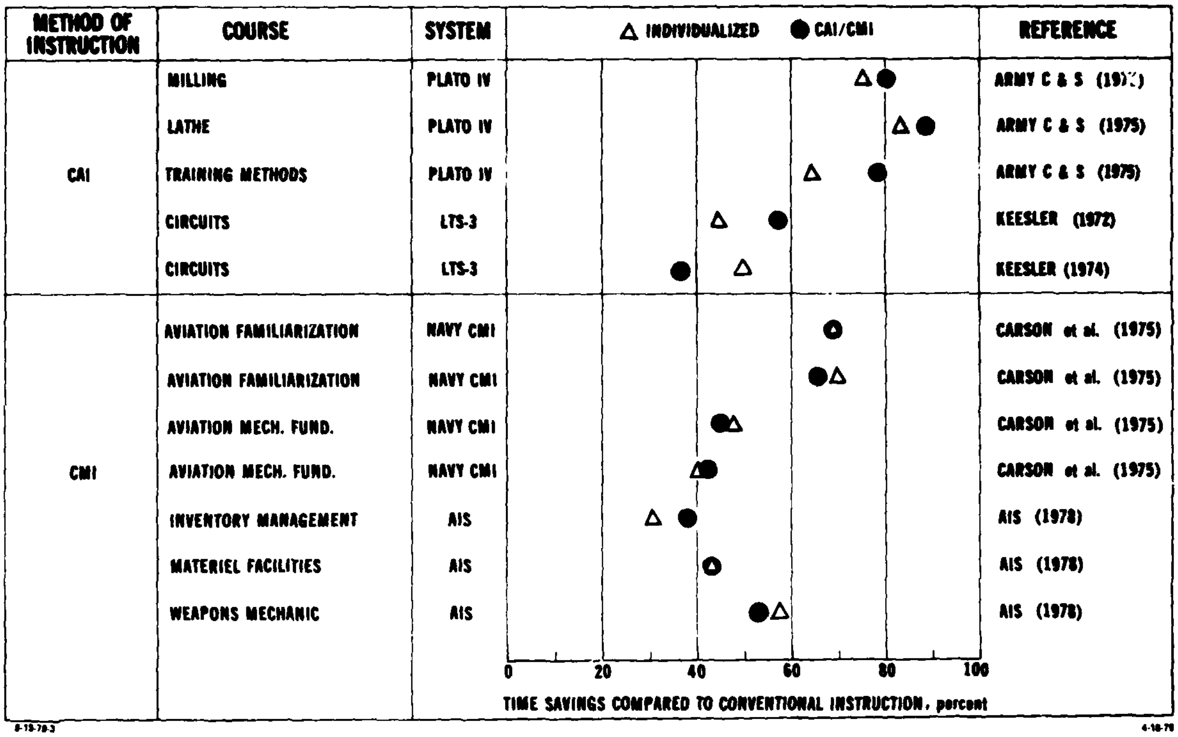


FIGURE 7. Amount of Student Time Saved, Compared to Conventional Instruction, by Individualized Instruction and by CAI or CMI on the Same Courses

Comparison of Time Savings Found with Individualized Instruction and Computer-Based Instruction. Student training time in courses can be reduced without the use of computer-based instruction, i.e., by individualized (or self-paced) instruction without computer support in place of conventional instruction. The question raised here is "what does computer support do that self-pacing does not do, at least with respect to the amount of student time saved?"

Figure 7 shows how much student time was required to complete twelve courses that were given, at various times, by conventional, individualized and CAI or CMI instruction. Only the percent time saved, compared to conventional instruction, is shown. There are only small differences between the amounts of student time saved by these three methods of instruction; the data are summarized in Fig. 8. Individualized instruction can save large amounts of the time required by students in conventional instruction (average savings of 50 percent or more in these samples). The addition of CAI to five individualized courses produced an additional average time saving of 5 percent; the addition of CMI to seven courses produced no additional average time saving. No significance can be placed on the differential effect of adding CAI rather than CMI to the base values because no course was given in both a CAI and CMI mode. The addition of computer support may or may not be economical, depending on its impact, in specific applications, on the numbers of instructors and support personnel, administrative costs and similar factors. The issue of cost is not addressed by these data.

| No. of Courses | Average Amount of Student Time Saved | | |
|---|---|---|---|
| | Individualized Instruction | CAI | CMI |
| 5 | 64% | 69% | - |
| 7 | 51% | - | 51% |

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FIGURE 8. Average Amount of Student Time Saved by Individualized Instruction and CAI or CMI in the Same Courses Compared to Conventional Instruction

Student Attrition. Since the method of instruction may influence the number of students who can successfully complete a course, the rate of academic attrition associated with alternative methods of instruction should be a matter of concern. Meaningful data on student attrition should come from a steady-state application of computer-based instruction and not from short-term experiments. This condition was met marginally by the Air Force Advanced Instructional System (AIS), where four courses were increasingly implemented in a CMI mode over the period of 1974-1978 and by the Navy Computer Managed Instruction System, where data are available on seven courses for 15 months after implementation in March 1977. It should be recognized that the rate of attrition observed in a course may also be influenced from time to time by policy decisions on standards for recruitment and the number of graduates to be produced by various courses. Such influences, if present, are not addressed here.

Figure 9 shows that academic attrition may have increased in the four courses on AIS during the period under observation. Note, however, that academic attrition appeared to rise in all (non-AIS) courses at Lowry AFB over the same period; thus, it is not necessarily true that the increased attrition in the AIS courses can be attributed primarily to the introduction of CMI.

Figure 10 shows academic attrition for seven courses before and after implementation on the Navy Computer Managed Instruction System. The average rate of attrition in these courses was 3.2 percent before and 4.6 percent after implementation in a CMI mode; it increased in six courses and decreased in one. Data on comparable courses not on CMI during the same period were not provided.

So far, only two CMI systems, the Air Force AIS and Navy CMI, have received some extended, though still limited, use in military training. Academic attrition may have increased in courses taught by CMI compared to attrition with conventional instruction. Since these comparisons do not take into account possible changes in the qualifications of students during the periods under observation, the available data suggest but do not prove that CMI may increase academic attrition over that found with conventional instruction.

Attitudes of Students and Instructors. Attitudes of students and instructors to CAI or CMI, in comparison with conventional instruction, are noted here only as qualitative aspects of these methods of instruction; they are not direct measures of effectiveness. Data on student attitudes are found in 39 of the 48 reports of military training summarized in this paper. As shown in Figure 11, students overwhelmingly prefer CAI or CMI to conventional instruction, or at least say so when asked; students are favorable to CAI in 29 of 40

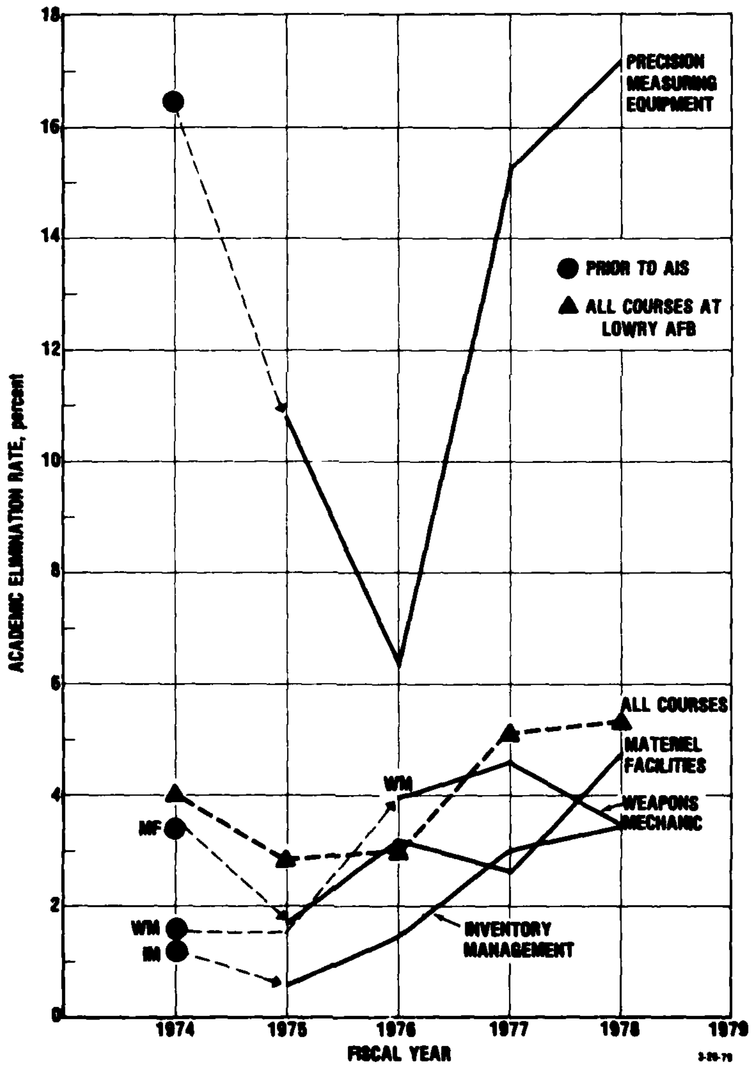


FIGURE 9. Academic Elimination Rate in Four Courses Before and After Implementation on AIS at Lowry AFB

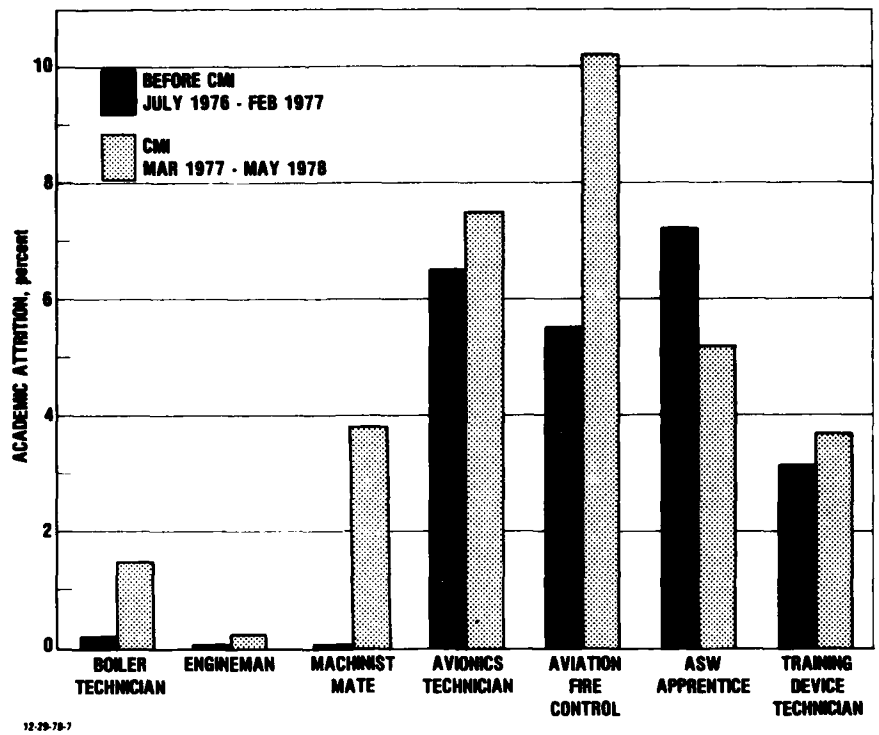


FIGURE 10. Academic Attrition in Seven Courses Before and After Implementation on Navy Computer Managed Instruction System

| Attitude to CAI/CMI | Students | | Instructors | |
|---|---|---|---|---|
| | CAI | CMI | CAI | CMI |
| Favorable | 29 | 8 | 1 | - |
| No difference | 1 | - | - | - |
| Unfavorable | 1 | - | 4 | 4[b] |
| No report | 9 | - | 39 | 4 |
| Total | 40 | 8 | 40 | 8 |

[a] All data are number of reports summarized in Appendix D.

[b] Favorable to CMI at first, changing to unfavorable by end of study.

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FIGURE 11. Attitudes of Students and Instructors Comparing CAI or CMI to Conventional Instruction in Military Training (a)

comparisons; they are unfavorable in one case and find no difference in another; no data are provided in 9 cases; they are favorable to CMI in all cases (N=8). Instructor attitudes are reported only in 9 of these 48 comparisons; instructors are unfavorable to CAI or CMI in 8 of these cases and favorable to CAI only in one.

Instructors of courses taught by CAI or CMI have not received much attention by researchers. The training of instructors is still oriented largely towards conventional instruction and instructors receive little guidance on how to properly conduct CAI or CMI courses.

## THE COST OF COMPUTER-BASED INSTRUCTION

The cost of computer-based instruction is not a popular subject for examination; only eight of the 30 studies cited above provide any cost data;

| RESOURCE (TYPE OR FUNCTION) | METHOD OF INSTRUCTION | | | | |
|---|---|---|---|---|---|
| | CONVENTIONAL INSTRUCTION | INDIVIDUALIZED INSTRUCTION | COMPUTER-BASED INSTRUCTION | | |
| | | | PLATO IV | NAVY CMI | OTHER[a] |
| **Program Development** | | | | | |
| Program Design | | | | | |
| Instructional Materials:[b] Conventional Instruction | | | | | |
| Individualized Instruction | | 4 | | | |
| Programming | | 1 | | | |
| First Unit Production[c] | | 2 | | | |
| Computer-Based Instruction | | | 4 | 1 | 3 |
| Programming | | | 2 | 2 | 2 |
| Coding | | | 2 | 2 | 2 |
| **Program Delivery** | | | | | |
| Instruction: Instructors | | | 1 | 2 | |
| Instructional Support Personnel[d] | | | | 1 | |
| Equipment and Services:[e] Laboratory (incl. simulators) | h | h | | h | |
| Media Devices | h | 3 | | h | |
| Computer Systems | | | 7 | 2 | 8 |
| Communications | | | 5 | | 2 |
| Materials (incl. Consumables)[f] | | | | | |
| Facilities[g] | | 1 | 2 | | |
| **Program Management and Administration** | | | | | |
| **Student Personnel:** Pay and Allowances | | | 1 | 2 | |
| Others (PCS, TDY, *etc.*)[i] | | | | 1 | |

NOTE: Shaded cells are not applicable. Blank cells indicate that relevant cost data are not available.

[a]Includes TICCIT, IBM 1500, LTS-3, GETS, and an experimental shipboard system.

[b]Includes revision.

[c]Master copy.

[d]All direct personnel not included in other categories.

[e]Includes all hardware related costs: initial (including installation and checkout), modification, and replacement; operation and maintenance; lease and user fees; computer system software; *etc.*

[f]Includes copies of instructional materials (books, courseware copies, *etc.*).

[g]Structures, fixtures, and furnishings.

[h]Laboratory equipment and media devices are applicable to all methods of instruction (except where simulated in CAI systems), and there is no reason why costs of their use would differ with method of instruction.

[i]Permanent change of station, temporary duty.

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FIGURE 12. Number of Sources of Data on Costs of Instruction

only five consider the cost-effectiveness of computer-based instruction.

Data on the Costs of Instruction. Figure 12 identifies the various resources needed to conduct instruction, broken down according to type or function. All methods of instruction require resources (for example, for program design, instructors, materials and facilities); CAI and CMI, in particular, require resources for computer systems and software. Relevant cost data could be found for some but not all of these types of resources. Figure 12 shows the number of sources of data we were able to find on the costs of each of these resources for various methods of instruction; blank spots indicate that relevant cost data could not be found. The data that were found were meager at best. These data are summarized in many tables in the original report. (1) The following points may be noted: (a) There are few data on the costs of conventional instruction and individualized instruction. (b) More cost data could be provided by converting student time savings into cost savings, on the basis of student pay and allowances. (c) There is no convenient way to summarize the available cost data in a single table.

The Cost of Computer Systems Hardware. There may be some interest in discussing the costs of central processors and terminal units, for selected instructional systems. The costs shown in Fig. 13 are limited to hardware and do not include the costs of preparing instructional materials, programming, instructors and the like; note that the cost data are for 1978 and some earlier dates.

System hardware costs can be expressed in three ways: (a) system procurement cost, (b) cost per terminal connected, and (c) cost per student-hour

| Method of Instruction | Computer System | Central Processor Cost (Thousands) | Terminal, Unit Cost (Thousands) | System Hardware Cost (Thousands) | System Hardware Cost Per Terminal (Thousands) | System Hardware Cost Per Student-Hour[a] |
|---|---|---|---|---|---|---|
| CAI | IBM 1500 32 Terminals[b] | – | – | $ 800 | $ 25 | $ 2.49 |
| | PLATO IV 1,000 Terminals[c] | $ 5,000 | $ 5.7 | 10,700 | 11 | 1.48[d] |
| | TICCIT 32 Terminals[e] | 760 | 2.9 | 850 | 27 | 2.66 |
| | 64 Terminals | 870 | 2.8 | 1,050 | 16 | 1.64 |
| | 128 Terminals | 970 | 2.8 | 1,330 | 10 | 1.04 |
| | GETS One Terminal | – | – | 34 | 34 | 3.40 |
| CMI | Navy CMI 6,000 Students[f] | 2,300 | 14.3 | 4,020 | 34 | 0.07 |
| | 16,000 Students[g] | 2,300 | 14.3 | 6,880 | 22 | 0.04 |

4-18-79

[a]2,000 hours per terminal per year for 5 years.
[b]Includes maintenance. Based on lease rates and amortizing equipment over a 5-year period, 1967, 1972, 1977.
[c]Control Data Corporation quotation, from private communication dated 14 August 1978.
[d]Based on 725 active terminal constraint.
[e]Hazeltine quotation, from private communication, 1978.
[f]128 terminals at 50 students per terminal, 1977.
[g]320 terminals at 50 students per terminal, 1977.
3-26-79-35

FIGURE 13. Costs of Computer Systems Hardware

(over some chosen amortization period). In terms of computer system hardware, procurement costs can range from about $35,000 (the stand-alone GETS) to over $10 million (a 1,000-terminal PLATO IV system), a factor of close to 300 times. On a per-terminal basis, there appears to be an inverse relationship between system size and cost. As an example, for the TICCIT system, the per-terminal system cost is $27,000 in a 32-terminal configuration and $10,000 in a 128-terminal configuration. This indicates a substantial economy of scale for larger systems.

A more meaningful relationship for comparing computer-based instruction with other methods of instruction is the cost per student-hour. Assume that terminals are used 2000 hours per year and that the system hardware lasts 5 years; then, the cost of hardware per student hour for CAI systems ranges from about $1.00 (for the 128-terminal TICCIT system) to $3.50 (GETS); PLATO IV costs about $1.50. The lower cost per student-hour associated with large systems implies a large initial commitment of funds (if central hardware is purchased) and a large commitment to CAI, with the other costs and risks it entails. Assuming that each CMI terminal would accommodate 50 students, student-hour costs for CMI would appear to be less than $0.10.

Note that the $3.50 associated with the GETS is based on information that is several years old. Systems of comparable capability, incorporating recent technological advances in microprocessors and data storage devices, can be anticipated to cost considerably less.

THE COST-EFFECTIVENESS OF CAI AND CMI

There have been only a few attempts to estimate the cost-effectiveness of CAI and CMI and these are based on incomplete analyses of the costs of instruction. Figure 14 summarizes the results of these studies. All of these studies are based on the premise that the amount of student training time saved by a method of instruction indicates major cost savings; the amounts of cost savings are estimated by computing the pay and allowances of students for the amounts of student time saved in training. The resultant amounts should more properly be called "cost avoidance savings". This procedure was applied to student time savings in studies of PLATO IV, Navy CMI, and AIS and, in one case, to revised course materials in a course given by conventional instruction. Four of these studies include some other costs, such as for preparing course materials, purchase or use of computers, and the number of instructors required by each method of instruction.

The dollar amounts of such "savings" could be large, depending, of course, on the number of students assumed for these estimates, e.g., about $10 million a year for about 50,000 students instructed in FY 1977 by the Navy CMI system and about $3 million a year for about 5,500 students instructed in FY 1978 by the Air Force AIS system. According to two cost-effectiveness evaluations that have been reported, the PLATO IV system was judged to be not as cost-effective as individualized instruction. These conclusions are based on incomplete cost data in two small-scale tests (535 students in four courses at U.S. Army Ordnance

| Method of Instruction | System | Service | Location | Time Savings (%) | Number of Courses | Number of Students in Experiments | Number of Students Assumed for Estimate | Estimated Savings Per Year | Reference |
|---|---|---|---|---|---|---|---|---|---|
| CAI | PLATO IV | A | Aberdeen | 65 - 80 | 3 | 535 | – | PLATO IV not cost-effective[1] | U.S. Army Ordnance Ctr. and School (1975) |
| | PLATO IV | N | No. Island | 67 | 1 | 22 | 200 pilots per year | $0.57M[2] | Crawford, Hurlock, Padilla and Sassano (1976) |
| | PLATO IV | AF | Chanute | 10 - 27 | 4 | 1261 | 375 per week | PLATO IV not as cost-effective as programmed instruction[3] | Dallman, DeLeo, Main and Gillman (1977) |
| Conventional (revised course) | – | N | Memphis | 50[4] | 4 | 400 | 300 per class per week | $ 6M[5] | Carson, Graham, Harding, et al. (1975) |
| CMI | Navy CMI | N | Memphis | 41 - 70 | 4 | 400 | 300 per class per week | $ 3M[6] | Carson, Graham, Harding, et al. (1975) |
| | Navy CMI | N | Memphis | – | – | – | –<br>–<br>52,672 graduates[8] (actual) | $ 8.9M FY 75[7]<br>$ 9.9M FY 76[7]<br>$10.0M FY 77[7] | Briefing material (1978)<br>Briefing material (1978)<br>Briefing material (1978) |
| | AIS | AF | Lowry | 24 - 36 | 4 | – | 21,128 (actual) | 1417 m/yrs<br>$ 6M (4 yrs) | Jul.1, 1974-Sept.31, 1978<br>Briefing material (1978) |
| | AIS | AF | Lowry | 10 - 52 | 4 | – | 5661 (actual) | 710 m/yrs<br>$ 3M[10] | Oct.1, 1977-Sept.31, 1978<br>Briefing material (1978) |
| | AIS. | AF | Lowry | -3.6 - 12.5[9] | 4 | – | – | AIS cost-effective compared to instructor-supported self-pacing on one course, not in others; computer costs small in comparison to other school costs | Feb. 1978-July 1978<br>AIS Service Test<br>Briefing material (1978) |

[1]Due to high communication and maintenance costs; PLATO IV cost-effective on basis of costs of developing and revising course materials; all comparisons with regard to self-paced instruction by sound-on-slide or television cassette.

[2]Pro-rated from cost avoidance of $5.7M over 10 years *provided* other training applications found to provide full-time utilization of PLATO IV terminals; the S-3A co-pilot training required only 8 percent of this capacity. Baseline was workbook and use of high-fidelity simulator of the Integrated Control System panel.

[3]Because of greater developmental and operating costs for PLATO IV.

[4]Compared to conventional instruction before revision.

[5]Savings due solely to course revision.

[6]Incremental to $6M above.

[7]Cost avoidance savings.

[8]Average on board, 6053.

[9]Comparison of manually self-paced instruction vs CMI in special test.

[10]Derived by pro-rating estimate shown above.

2-7-79-4

FIGURE 14. Summary of Studies Reporting Cost Savings and/or Cost-Effectiveness of Various Methods of Instruction

Center and School, Aberdeen Proving Ground, Maryland, 1975; 1261 students in four courses at Chanute AFB, Illinois, 1977). The Air Force AIS was found to be cost-effective, compared to instructor-supported, self-paced instruction in one course (Inventory Management) but not in three others; the computer costs which made the latter courses not cost-effective were judged to be small in comparison to other school costs (AIS Service Test, 1978). Since all of these results are based on incomplete cost data, the findings should not be generalized or taken as conclusive.

Other benefits, beyond those of saving student training time, are often said to occur with CAI or CMI, because of the many services that can be provided by a computer. The following list illustrates a variety of claims that have been made:

1. More precise data for improving and updating course materials
2. Improved control over equipment, facilities and materials for instruction
3. Improved allocation of resources among students
4. Improved ability to accommodate fluctuations in student loads
5. Reduced instructor:student ratios (including the ability to use less-qualified instructors)
6. Reduced need for support by non-instructional personnel
7. Reduced time of students on base waiting for courses to start
8. Reduced time of students on base waiting for travel orders after completing courses
9. Improved integration of personnel records of students at school
10. Improved utilization of instructors.

Few of these potential benefits have been included in any cost-effectiveness evaluation known to us. The AIS Service Test (1978) estimated the numbers and costs of instructors required for individualized and computer-managed instruction by observing what instructors were doing in each case. Records kept on the AIS show that the amounts of time spent by students at Lowry AFB waiting to enter a course and waiting for an assignment after completing a course have been reduced for those instructed by AIS. Records kept by the Navy CMI system show that, because of course time reductions, the average on board count of students in school has been reduced for those instructed by that system. However, the cost savings, if any, implied by these reductions were not included in any of the cost-effectiveness analyses.

## CONCLUSIONS

1. Measures of Effectiveness. The effectiveness of computer-assisted and computer-managed instruction for military training has been measured only by student achievement at school and not by performance on the job. Correlations between performance at school and on the job have not been established for any method of instruction.

2. Student Achievement at School. Student achievement in courses at military training schools with computer-assisted instruction is the same as or greater than that with conventional instruction; the amount of additional achievement is small and has little practical importance. Student achievement in courses with computer-managed instruction is about the same as that with conventional instruction. Both of these results are due to keeping students in CAI and CMI courses until they achieve standards set previously for conventional instruction.

3. Student Time Savings. Computer-assisted and computer-managed instruction in military training save about 30 percent of the time (median value) needed by students to complete the same courses given by conventional instruction. The amounts of student time saved by computer-based instruction vary widely, but little attention has been given to the factors that could account for the wide variation. Most of the results on computer-assisted instruction come from experiments of limited duration, with limited amounts of course materials, and with relatively few students. Where computer-managed instruction has been used for extended periods (up to 4 years), the initial time savings have been maintained or increased.

4. Individualized and Computer-Based Instruction. Individualized instruction (self-paced instruction without computer-support) saves student time; little or no additional student time is saved when the same courses are given by computer-assisted or computer-managed instruction.

5. Student Attrition. Computer-managed instruction may increase the rate of student attrition for academic reasons, compared to that with conventional instruction. However, the observed increases in attrition may also be due to decreases in student quality; the influence of this factor has not been carefully examined. No data have been reported on student attrition with computer-assisted instruction.

6. Student and Instructor Attitudes. Attitudes of students toward computer-assisted and computer-managed instruction appear to be favorable. Attitudes of instructors are reported as unfavorable, but this finding is based on very limited data. Little attention has been given to the role of instructors in computer-based instruction and to how they should be prepared for this method of instruction.

7. Cost Data. Only limited and incomplete data are available on the costs of computer-assisted and computer-managed instruction in military training. Data that are collected routinely on the costs of operational training programs are too highly aggregated, particularly with respect to training support functions, for use in analytical comparisons of computer-based instruction with conventional instruction.

8. Cost-effectiveness. Estimates based on the amounts of student time saved suggest that the Navy Computer Managed Instruction System avoided costs of about $10 million in FY 1977 and that the Air Force Advanced Instructional System avoided costs of about $3 million in FY 1978. These estimates are incomplete because they do not consider all of the costs of providing computer-managed instruction at these installations or compare these costs with the costs of alternative methods of instruction for the same courses.

## REFERENCES

1. This paper is based on a study performed for the Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology). See Jesse Orlansky, and Joseph String, "Cost-effectiveness of Computer-Based Instruction for Military Training", IDA Paper P-1375, Institute for Defense Analyses, Arlington, Virginia 22202, April 1979 (DDC AD 073 400).

2. Military Manpower Training Report for FY 1981, Department of Defense, March 1980, p. III-3, V-4 to V-11, 6, 4.

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# ESTABLISHING THE TRAINING COST FOR A COMPLEX WEAPONS SYSTEM: AN EXAMPLE USING THE P-3 FRS

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This paper describes an approach of establishing the training cost for a complex weapons system. The Navy P-3 Training Program in VP-30 and VP-31 was used as a model in establishing the cost parameters. In this program over 5,691 training objectives were developed stretching over seven crew positions and a multitude of training tracks. This paper will show how costs were developed for each crew position describing the costs for learning center, for weapon system trainer, for cockpit procedure trainer, for position trainer and for the aircraft itself.

## INTRODUCTION

### Problem and Overview

This paper describes, using the example of the Navy's ASW Patrol Fleet Replacement Squadron (FRS), Patrol Squadron 31 (VP-31), a model for estimating the training costs for a complex weapons system. It is not a definitive list of all costs nor does it attempt to account for all costs in the Patrol FRS. It does, however, account for the major cost contributors and give a framework for gathering and estimating them.

The manager for a complex weapons system training organization currently makes major decisions affecting syllabus changes without, in many cases, realizing the impact of these decisions on the total training system cost. A training squadron often has cognizance of but a limited part of the total syllabus costs, usually aircraft direct operating costs. The costs for the instructor salaries, training devices, Instructional Systems Development (ISD) efforts, and student time are not visible, and thus are often discounted.

Consideration by the training manager should be given to the costs in making changes to the syllabus as well as their instructional implications. The Defense Science Board placed considerable emphasis on the need to make cost benefit analysis when making training management decisions (1).

### Background

Previous studies have been found that bring a methodology to bear on the problem in part, but none have application for the operational user. Doughty, Stern, and Thompson (2) have developed a guideline for cost analysis in a typical U.S. Navy "A" School but their study did not adequately reflect the ISD acquisition costs, or the costs relevant to more exotic hands-on media such as flight simulators and aircraft flight hours. They also do not cover multiple training tracks and the interaction of media versus training tracks resulting from multicrewed systems. Orlansky and String (3, 4) give a rather complete generalized model for estimating training costs. However, they do not apply their model in a complete manner to a specific Navy training application. Allbee and Semple (5) have developed an extensive cost model using various U.S. Air Force examples which do not apply to Navy fleet training due to the differing data source bases between Air Force and Navy data files. The Allbee and Semple cost model does render valuable insights for the development of cost models. However, the model is too detailed for use by fleet training squadrons, in that it takes into account some variables that are not useful at the FRS. An example of this is the factoring into the model the costs of such items as the Air Staff and Higher Headquarters.

Existing studies approaching the data for fleet level use are either outdated or incomplete. Browning, Ryan, Scott, and Smode (6) were not tasked to look at any media except the 2F87F simulator, and did not make comparisons in other than the pilot training track. The cost data in the study were also based on July 1976 dollars. Braby, Henry, and Morris (7) indicate some guidelines for costing media alternatives that are helpful in isolating costs of conventional media. Goclowski, King, Ronco, and Arkren (9) have described a model identifying system ownership costs (SOC). Their SOC model is a good reference in attempting to establish a generality for identifying cost drivers in a complex training system.

The present study is not a new approach to the data in the aggregate but represents a refinement of existing models for the user in the fleet readiness squadron.

## DEVELOPMENT OF THE MODEL FOR ESTIMATING P-3 TRAINING COSTS

This section describes a model for estimating the training costs for the VP Fleet Replacement Squadrons (FRS), VP-30 and 31. It includes certain simplfying assumptions that will be discussed below. However, it is important to note that the major cost drivers have been identified and are shown as variables. This model follows the construct of Orlansky and String (3, 4) in that it does not display sensitivity to the timing of costs or to budget implications of program alternatives. It serves as a general structure for estimating training costs.

### Student Load

The determination of student quotas for this model was reported by Thode (10). The quotas are displayed for a one-year period by position for one FRS, and for both FRSs. Also shown are data for 15 years. 15 years is required for later calculations for estimating the revision costs of the ISD material and the life-cycle costs of certain media.

TABLE 1

NOMINAL STUDENT LOAD

| | 1 YEAR | | 15 YEARS |
|---|---|---|---|
| POSITION | One FRS | Both FRS | |
| Pilot | 180 | 360 | 5,400 |
| NFO | 120 | 240 | 3,600 |
| FE | 140 | 280 | 4,200 |
| SS 1/2 | 120 | 240 | 3,600 |
| SS 3 | 60 | 120 | 1,800 |
| COMM | 40 | 80 | 1,200 |
| ORD | 120 | 240 | 3,600 |
| | Total all years | | 23,400 |

A simplifying assumption has been made as it pertains to student load. Student attrition has not been accounted for. It is estimated that attrition is of minimal significance for the VP cost model. If, however, attrition is of program significance it can be accommodated by adding to the student load an additional student quota that represents the impact of each loss on the total load. For a more complete discussion of attrition see Orlansky and String (3).

### Description of Demand Created by Current Syllabus

The Master Course Syllabus (MCS) (8) describes each hour of instruction for all media and crew positions. Crew positions are described by type of aircraft (P-3B or P-3C) as well as by job title. The MCS is summarized in Table 2. The number of instructional objectives for each crew position is taken from CO VP-31 LTR (11). The media shown include learning center activities, the numerical designations of training devices and simulators, and the P-3 itself.

TABLE 2

SUMMARY OF MASTER COURSE SYLLABUS

| CREW POSITION | # OBJECTIVES | | SYLLABUS HOURS BY MEDIA | | | | |
|---|---|---|---|---|---|---|---|
| | Total | LC | 2C45/69 | 2F87F | 14B44 | 2F87T | P-3 |
| Pilot | | | | | | | |
| 1st Tour | 1000 | 248 | 22 | 28 | 3 | 32 | 95 ʼB-20) |
| 2nd Tour[a] | | 239 | 9 | 30 | -- | 32 | 50 B-15) |

*B = B Stage Hours

TABLE 2 (Continued)

| CREW POSITION | # OBJECTIVES | SYLLABUS HOURS BY MEDIA | | | | |
|---|---|---|---|---|---|---|
| | | LC | 2C45/69 | 2F87F | Static/A/C | P-3 |
| FE[b] | 413 | 265 | 8 | 36 | 11 | 104 (B-40) |

| CREW POSITION | # OBJECTIVES | LC | P-3 LAB | 2F69 | 2F87T | P-3 |
|---|---|---|---|---|---|---|
| NFO B[a] | 843 | 252 | 21 | 69 | --- | 70 |
| C[a] | 869 | 386 | 27 | -- | 74 | 54 |

| CREW POSITION | # OBJECTIVES | LC | 14B44 | 2F69 | 2F87T | A/C LAB | P-3 |
|---|---|---|---|---|---|---|---|
| SS 1/2 B | 575 | 236 | 57 | 32 | -- | 20 | 36 |
| C | 605 | 229 | 54 | -- | 32 | 35 | 30 |

| CREW POSITION | # OBJECTIVES | LC | 14B40 | 2F69 | 2F87T | 15Z1 | 15E16 | A/C LAB | P-3 |
|---|---|---|---|---|---|---|---|---|---|
| SS 3 B | 298 | 98 | -- | 32 | -- | 9 | 11 | 26 | 70 |
| C | 366 | 154 | 36 | -- | 32 | -- | -- | 25 | 70 |

| CREW POSITION | # OBJECTIVES | LC | Static/A/C | A/C LAB | P-3 |
|---|---|---|---|---|---|
| ORD B | 199 | 44 | 33 | 18 | 24 |
| C | 209 | 40 | 31 | 15 | 24 |
| COMM B | 345 | 130 | 17 | 51 | 30 |

TOTAL -- Hours of Developed Instruction by Media

| | | |
|---|---|---|
| Number of Learning Objectives | | 5,691 |
| Learning Center Hours of Instruction | | 2,321 |
| Syllabus Hours Assigned to | 2C45/69 | 79 |
| | 2F87F | 94 |
| | 2F87T | 205 |
| | 2F69(T) | 133 |
| | 14B44 | 114 |
| | P-3 | 657 |
| | P-3 (Lab) | 228 |
| | P-3 (Static) | 92 |
| | 14B40 | 36 |
| | 15Z1 | 9 |
| | 15E16 | 11 |

Notes:
a = Tactical Team Training An Additional 54 hours
b = NAMTRADET an Additional 160 hours
c = Pilot 1st and 2nd tour objections are not differentiated

Table 3 shows the instructor-to-student ratio required by various generic hands-on media. This ratio will be used later in the cost estimating section. The cost for the learning center is described along with the assumptions in the cost estimating section.

The instructor/student ratio is only part of the resource factor for a P-3 sortie. A similar concern is the number of crew positions that benefit from any flight training hour. An analysis of the MCS suggests the following allocation of flight hours per position.

| Position | Proportion of Flight Hours |
|---|---|
| MCS Phase B | |
| Pilot | .5 |
| FE | .5 |
| MCS Phase C & D | |
| All | .14 |

TABLE 3

INSTRUCTOR/STUDENT RATIO FOR HANDS-ON MEDIA

| Position | OFT/PT | WST | P-3 |
|---|---|---|---|
| 1. Pilot | .5 | .5 | 1 |
| 2. NFO | 1 | 1 | 1 |
| 3. FE | .5 | .5 | .5 |
| 4. SS 1/2 | .25 | .5 | .5 |
| 5. SS 3 | .5 | 1 | .5 |
| 6. COMM | -- | -- | .5 |
| 7. ORD | -- | .3 | .5 |

REF: Welch (12)

(For example: The ratio of a syllabus flight hour for a pilot student to an instructor flight hour is 1 to 1).

For Phase B flight hours during familiarization the MCS shows that one pilot and one FE are trained. Therefore, each should share in the demand for that flight hour, and the proportion for each is one-half (.5). In C and D stages, however, all crew members are receiving training of some type, and it is assumed that the flight hour costs are spread across all positions. This data will then be used in the establishment of costs for flight hours.

## Estimating Training Costs

The example shown below is a method of establishing training costs. Certain simplifying assumptions have been made, and they will be discussed. The cost "driver" will be discussed in the five sections. Section 1 provides the costs of instructional systems development. Section 2 shows the learning center costs. The training device costs are given in Section 3. Section 4 shows the P-3 aircraft costs, and Section 5 provides the instructor costs.

The costs shown below are an approximation of the "level of effort" for each cost category. They show the approximate cost "drivers" in the VP FRS. It was deemed impractical to attempt to ascertain the small cost differences among some P-3 model types, e.g., one P-3C was considered, not all the variations of P-3C, Update I, Update II and so forth. Also, all pilot costs assumed the P-3C, not P-3B or update syllabi.

Other simplifying assumptions are as follows:

1. Due to the lack of data, costs were not identified for VP-30 and 31 instructor training. The high turnover of pilot instructors might make this a cost category that should be developed in the future.

2. As was explained in an earlier section, student attrition was assumed to be zero. If there is in fact a significant student attrition in some tracks, the time where attrition occurs and the percentage of course completion needs to factored into the student costs

3. Administrative overhead, flights aborted due to equipment malfunctions, out of maintenance check flights, and instructor NATOPS/instrument check flights have not been included as student flight hours.

4. Except as noted, costs have not been established for some student categories such as 2nd tour NFO, 2nd tour FE, NARF test pilots, or other rare categories.

5. The total overhead of indirect administration has been eliminated for simplicity although it could be added if desired. The

overall proportional costs between media, however, would probably remain unchanged. Some of the administrative overhead factors that were not addressed are Squadron, Wing, COMNAVAIRPAC, and FASOTRAGRUPAC, administration and headquarters costs. Allbee and Semple (5) gives an example of USAF training cost and does include costs of some of the higher headquarters.

6. P-3 aircraft costs were developed as shown from the NALCOMIS (Commander Naval Air Systems Command) report (13), but depreciation was not added to the calculation. Depreciation is deemed to be not relevant in consideration of the cost of the P-3. Obsolescence due to its mission capability probably occurs prior to its max airframe life. However, if aircraft depreciation is desired, Orlansky (3) shows programmed flying hours to be 429 per year, aircraft acquisition $8,280,000 and service life 15 years. This yields a straight line depreciation of $552,000 per year or $1287 per aircraft hour.

7. Costs for military construction have not been included in the model except for the modification to the learning center. The Moffett learning center costs were included for they were a major cost in the establishment of the revised P-3 curriculum. It was also assumed that the learning center costs at NAS Moffett Field were representative of the costs at NAS Jacksonville, FLA.

8. Costs were assumed to be in constant dollars. It is obvious that they are rapidly changing in the current environment. However, for the purposes of this model relative costs across media are important, not absolute costs. For the same reason costs were not discounted for future years in accordance with DODI 7041.3.(14)

9. Allowance has not been made for any major changes in the future to the P-3 aircraft. If perchance, a P-3D or P-3C Update IV is developed the ISD update costs for new equipment or a new aircraft (e.g., P-4A) would require a new cost estimation. The addition of a new aircraft, new equipment, or major software changes to the existing aircraft requires a reevaluation of the costs. The current aircraft mix except where noted for Table 6 represents the base line for this report.

10. All data shown in the report except ISD costs (Table 8) are for NAS Moffett Field, California, only and costs for NAS Jacksonville, Florida, are probably about the same. It is, therefore, assumed that there *are not significant differences* between training sites.

## Instructional System Development Costs

The ISD cost will be discussed in two general areas: first, the initial ISD cost; and second, the costs required to maintain curriculum currency. These two cost areas will then be displayed in a table showing the ISD costs per student.

### Initial Costs

The initial contractor cost for the P-3 activities was determined from the contract. The VP ISD team personnel costs, table 4, were developed based on Welch (12) for the staffing and man-years, and by using Koehler (15, 16) for billet costs. The research psychologist/educational specialist man-years and billet costs are from Thode (10).

The category of other media costs shown in table 5 accounts for audio-visual services performed by the U.S. Navy, and for reproduction costs of the A/V productions (10). CO VP-31 LTR (11) is the reference for all other data in table 5.

### Maintenance Costs

A training program for a fleet aircraft is not an unchanging, static syllabus of instruction. Walker (17) evaluated an ISD activity for training crew members to fly a U.S. Navy fleet aircraft (S-3A) with a similar mission to the P-3. The results of this study showed that over a two-year period 22 percent of the media required change either due to content, learning strategy or media related issues. Table 6 assumes that a significant effort is involved in maintenance of the curriculum, an effort which decreases over time. For it is assumed that during years 1-5 the current ISD staff shown on table 6 will be required to revise/update the instruction. The staffing plan for the initial years after introduction of the ISD syllabus was based, in part, on recommendations developed by Walker (17). (NPRDC developed the staffing recommendations (18).) For years 6-10 the requirement for the maintenance of P-3B instruction has been deleted from the revision staff, and for years 11-15 only minor revisions of instruction for crew members of the P-3C are assumed.

TABLE 4

VP ISD TEAM PERSONNEL COSTS

| RANK/RATE | DESIGNATION/ RATING | MY | COST |
|---|---|---|---|
| O-4 | 1320 | 8 | $ 270,072 |
| O-3 | 1310 | 16 | 1,205,552 |
| O-3 | 1320 (P-3B) | 17 | 496,366 |
| O-3 | 1320 (P-3C) | 16 | 467,168 |
| E-7 | AW | 4 | 107,060 |
| E-6 | AW SS/3B | 6 | 138,828 |
| E-6 | AW SS/3C | 6 | 138,828 |
| E-6 | AW SS 1/2 | 17 | 393,346 |
| E-6 | AO | 8 | 223,024 |
| E-7 | AD | 3 | 95,370 |
| E-6 | AD | 10 | 280,340 |
| E-5 | AT | 4 | 94,488 |
| E-5 | DM | 4 | 63,276 |
| E-3 | DM | 6 | 71,100 |
| Civilian | GS 11/12 | 13 | 700,000 |
| | | | $4,544,818 |

NPRDC

GS-12 Research Psychologists $50,000 10 Man-years $500,000

NOTE: Personnel based on personal communication with Thode (10) and LCDR Welch (12).

TABLE 5

ISD DEVELOPMENT COSTS SUMMARY

| | |
|---|---|
| Courseware Contract | $2,947,626 |
| VP ISD Team Personnel Costs | 4,544,818 |
| Other Media Costs | 503,792 |
| | $7,996,236 |
| TOTAL # of Training Objectives in VP Curriculum | 5,691 |
| TOTAL # of Hours of Instruction in VP Curriculum All Tracks | 5,463 |

$$\frac{\text{Development Cost}}{\text{Instructional Hours}} = \text{Cost Per Hour for Development}$$

$$\frac{\$7,986,236}{5463} = \$1,464$$

TABLE 6
ISD UPDATE COSTS

VP 31/FASO ISD UPDATE PERSONNEL YEAR 1-5

| # | Rank/Rate | Designator | Title | VP-31 | FASO | Billet Cost |
|---|---|---|---|---|---|---|
| Administrative-Support Staff | | | | | | |
| 1 | LCDR | 1320 | ISD Team Director | x | | $ 33,759 |
| 1 | LCDR | 1310 | Asst Team Director | x | | 69,559 |
| 1 | LT | 1310 | Syllabus Director | x | | 75,347 |
| 1 | LT | 1320 | Syllabus Director | x | | 29,198 |
| | | | SUB TOTAL | | | $207,863 |
| SUBJECT MATTER EXPERT | | | | | | |
| 1 | LT | 1310 | B Pilot | x | | $ 75,347 |
| 1 | LT | 1310 | C Pilot | x | | 75,347 |
| 2 | LT | 1320 | B NFO | x | | 58,596 |
| 1 | LT | 1320 | B NFO | | x | 29,198 |
| 2 | LT | 1320 | C NFO | x | | 58,596 |
| 1 | LT | 1320 | C NFO | | x | 29,198 |
| 3 | AW-1 | | SS 1/2 | x | | 69,414 |
| 2 | AW-1 | | SS 1/2 | | x | 46,276 |
| 1 | AWC | | SS 3 | x | | 26,765 |
| 1 | AW-1 | | SS 3 | x | | 23,138 |
| 1 | AW-1 | | SS 3 | | x | 23,138 |
| 1 | AOC | | C ORD | x | | 34,342 |
| 1/2 | AO-1 | | B ORD | x | | 13,939 |
| 1 | ADCS | | FE | x | | 33,933 |
| 1 | AD-1 | | FE | x | | 28,034 |
| 1 | AR-1 | | B Comm | x | | 30,689 |
| | | | SME SUB TOTAL | | | $655,950 |

Civilian Staff

| # | Position | Cost |
|---|---|---|
| 1 | GS-11 Educational Specialist | $24,200 |
| 1 | Civilian Editor | 14,600 |
| | | $38,800 |

| | |
|---|---|
| Total Military costs | $863,813 |
| Cost Adjusted by .58 Factor (see text) | -362,801 |
| Adjusted Cost | 501,012 |
| Civilian Staff Cost | 38,800 |
| Yearly Cost (years 1-5) | $539,812 |

| # | Rank/Rate | Designator | Title | VP-31 | FASO | Billet Cost |
|---|---|---|---|---|---|---|
| Administrative-Support Staff | | | | | | |
| 1 | LCDR | 1320 | ISD Team Director | x | | $ 33,759 |
| 1 | LCDR | 1310 | Asst Team Director | x | | 69,559 |
| 1 | LT | 1320 | Syllabus Director | x | | 29,198 |
| | | | ADMINISTRATIVE SUB TOTAL | | | $132,516 |

TABLE 6 (Continued)

VP-31/FASO ISD UPDATE PERSONNEL YEAR 6-10

Subject Matter Experts

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | LT | 1310 | C Pilot | x | | $ 75,347 |
| 2 | LT | 1320 | C NFO | x | | 58,596 |
| 1 | LT | 1320 | C NFO | | x | 29,198 |
| 3 | AW-1 | | S3 1/2 | x | | 69,414 |
| 2 | AW-1 | | S3 1/2 | | x | 46,276 |
| 1 | AWC | | SS 3 | x | | 26,765 |
| 1 | AW-1 | | SS 3 | x | | 23,138 |
| 1 | AW-1 | | 22 3 | | x | 23,138 |
| 1 | AOC | | C ORD | x | | 34,342 |
| 1 | ADC3 | | FE | x | | 33,933 |
| 1 | AD-1 | | FE | x | | 28,034 |
| | | | SME SUB TOTAL | | | $448,181 |

Civilian Staff

| | | |
|---|---|---|
| 1 | GS-11 Educational Specialist | $24,200 |
| 1 | Civilian Editor | 14,600 |
| | | $29,800 |
| | Total Military Costs | $580,697 |
| | Cost Adjusted by .58 Factor (see text) | -243,893 |
| | Adjusted Cost | 336,804 |
| | Civilian Staff Cost | 38,800 |
| | Yearly Cost (years 6-10) | $375,604 |

| # | Rank/Rate | Designator | Title | VP-31 | FASO | Billet Cost |
|---|---|---|---|---|---|---|
| **Administrative Support Staff** | | | | | | |
| 1 | LCDR | 1320 | ISD Team Leader | x | | $ 33,759 |
| 1 | LT | 1310 | Syllabus Director | x | | 75,347 |
| | | | ADMINISTRATIVE SUB TOTAL | | | $109,106 |
| **Subject Matter Experts** | | | | | | |
| 1 | LT | 1310 | C Pilot | x | | $ 75,347 |
| 1 | LT | 1320 | C NFO | x | | 29,198 |
| 1 | LT | 1320 | C NFO | | x | 29,198 |
| 1 | AW-1 | | SS 1/2 | x | | 23,138 |
| 1 | AW-1 | | SS 1/2 | | x | 23,138 |
| 1 | AWC | | SS 3 | x | | 26,765 |
| 1 | AW-1 | | SS 3 | | x | 23,138 |
| 1 | AOC | | C ORD | x | | 34,342 |
| 1 | AD-1 | | FE | x | | 28,034 |
| | | | SME SUB TOTAL | | | $292,298 |

Civilian Staff

| | | |
|---|---|---|
| 1 | GS-11 Educational Specialist/ Editor | $24,200 |
| | Total Military Costs | 401,404 |
| | Cost Adjusted by .58 Factor (see text) | 168,590 |
| | Adjusted Cost | $232,814 |
| | Civilian Staff | 38,800 |
| | Yearly Cost (years 11-15) | $276,614 |

TABLE 6 (Continued)

VP-31/FASO ISD UPDATE PERSONNEL YEAR 11-15

TOTAL ISD UPDATE COSTS

| Year | Per Year | Total |
|---|---|---|
| 1-5 | $539,812 | $2,699,060 |
| 6-10 | 375,604 | 1,818,020 |
| 11-15 | 276,614 | 1,383,070 |
| | | $5,960,150 |

Table 6 thus portrays the cost for the VP-31/FASOTRAGRUPAC ISD Update based on the current staffing, and on future projections. The staffing is shown in three categories, administrative support, subject matter experts, and civilian. A pair of columns show if the staff position is at VP-31 or FASOTRAGRUPAC. The billet costs are from Koehler (15, 16).

The military billet costs as they affect this model have been reduced by .58. NPRDC (18) has calculated that each military member of the ISD staff will be devoting 150 days per year to revision/update duties. Since there are 260 working days in a year this, then, works out to approximately a ratio of .58 to one man-year. Military duties, leave, TAD, flying, and other duties account for the remaining days.

ISD Cost Summary

The total ISD costs, then, can be developed by adding the total costs of the development and the costs of the maintenance requirements. The ISD cost per instructional hour or per learning objective is found by dividing the number of hours or objectives into the total ISD cost as shown in table 7.

The cost per student for ISD is then found by:

1. Determining the percentage a specific track is of the total training (in this case by percentage of training objectives represented by each training track). The number of objectives per track is found in table 2.
2. Determining the total number of students in each track over the 15 years of estimated life from table 1.
3. Dividing cost per track by the total number of students in the track.

TABLE 7

TOTAL ISD COSTS

| | | |
|---|---|---|
| Development | | $ 7,966,236 |
| Update | | 5,560,150 |
| | TOTAL | $13,556,386 |

$$\frac{\text{ISD Cost}}{\text{Instructional Hour}} = \text{Total ISD Cost Per Hour} \qquad \frac{\text{Total ISD Cost}}{\text{Objective}} = \text{Total ISD Cost Per Obj.}$$

$$\frac{\$13,556,386}{5463} = \$2,481 \qquad \frac{\$13,556,386}{5691} = \$2,382$$

These data showing cost per student are shown for each track in table 8. For simplicity no differentiation was made between P-3B, P-3C, Update I, II, etc. The ISD costs for each aircraft type overlap a great deal and their relative cost differences would not greatly change the overall relationship among media.

### Learning Center Costs

FASOTRAGRUPAC maintains a learning center at VP-31 and both VP-31 and FASOTRAGRUPAC provide instructors to support the instruction. The costs for the learning center (LC) have been allocated in the following manner. Although this calculation is shown for one site the costs for both sites is assumed to be the same.

Milcon and Equipment. The learning center has 198 carrels. For this model it is assumed that the LC and its associated equipment will have a 10 year useful life. The initial milcon and equipment costs were about $600,000. The investment costs then of the LC are $60,000 per year. For further discussion about milcon costs see Allbee and Semple (5).

LC Support Costs. The LC support costs for FY 79 are reported below and were supplied by FASOTRAGRUPAC (19). FASOTRAGRUPAC reports military costs by using NAVCOMPNOTE 7041, the composite standard military rate table. This table only accounts for pay and allowances, not the overhead which is represented in the Koehler (15, 16). The latter appear to be a more accurate reflection of the actual costs. An example is that they include the cost for pilot training for the billet cost of a pilot, NFO training for NFO, etc. If NAVCOMPNOTE 7041 is used for a Lieutenant it shows a yearly cost to be $24,611; Koehler (15) shows a pilot to cost $75,347 and a NFO to cost $29,198 per year. Billet costs for civilians rate are under development and should be used in future models (20). The FASOTRAGRUPAC (19) figure for overhead for civilians is too low at 10%. A sample check with Koehler (20) shows that to be an underestimate of about 10-20 percent.

TABLE 8

ISD COST PER CREW POSITION

| Position | % of Training Objectives | % of Cost | Total Students | Cost Per Student ($) |
|---|---|---|---|---|
| Pilot | 26 | $ 3,524,660 | 5400 | 653 |
| NFO | 23 | 3,117,969 | 3600 | 866 |
| FE | 11 | 1,491,202 | 4200 | 355 |
| SS 1/2 | 16 | 2,169,022 | 3600 | 603 |
| SS 3 | 10 | 1,355,639 | 1800 | 753 |
| COMM | 9 | 1,220,075 | 1200 | 1017 |
| ORD | 5 | 677,219 | 3600 | 188 |
| TOTAL COST | | $13,556,386 | | |

The cost categories are: graphics personnel, duplication personnel and supplies, and LC staff. The graphics and duplication personnel are required to update and reproduce the AV and printed instructional materials. The FASOTRAGRUPAC budget for learning center applicable supplies is added at this point to LC costs. The LC staff consists of those civilian and military personnel who issue materials and maintain the learning center. Table 9 shows the cost of the LC not including the instructors.

TABLE 9

LEARNING CENTER SUPPORT COSTS PER YEAR

Graphics Personnel at FASO Moffett

| GRADE/RATE | NUMBER | PER YEAR | OVERHEAD | TOTAL |
|---|---|---|---|---|
| GS-9 | 1 | 18739 | 10% | $ 20,612 |
| GS-7 | 4 | 15317 | 10% | 67,394 |
| GS-5 | 2 | 12368 | 10% | 27,209 |
| GS-4 | 1 | 11054 | 10% | 12,159 |
| | | | TOTAL | $127,376 |

Duplication Personnel at FASO Moffett

| | | | | |
|---|---|---|---|---|
| LI 2 | 3 | 15567 | INC | $ 46,701 |
| SN (LI) | 2 | 11848 | INC | 23,676 |
| | | | TOTAL | $ 70,397 |

| | | | | |
|---|---|---|---|---|
| LC Supplies | | | | $ 60,000 |

Learning Center Staff

| | | | | |
|---|---|---|---|---|
| Civilian | | | | |
| GS-5 | 1 | 12368 | 10% | $ 13,604 |
| GS-3 | 1 | 9846 | 10% | 10,830 |
| GS-2 | 2 | 8902 | 10% | 19,584 |
| GS-4 | 1 | 11054 | 10% | 12,159 |
| Military | | | | |
| YN 2 | 1 | 15347 | INC | 15,347 |
| AZ 3 | 1 | 14971 | INC | 14,971 |
| AA (AZ) | 3 | 13878 | INC | 41,634 |
| | | | TOTAL | $128,131 |

Total Noninstructor Learning Center Costs Per Year

| | |
|---|---|
| MILCON and Equipment Per Year | $ 60,000 |
| Graphics Personnel | 127,376 |
| Duplication Personnel | 70,397 |
| Supplies | 60,000 |
| LC Staff | 128,131 |
| TOTAL | $326,024 |

$$\frac{\text{Total LC noninstructor cost}}{\text{Total Number of Students}} = \text{Total noninstructor cost per student}$$

$$\frac{\$326024}{780} = \$418$$

### Instructor Costs

The learning center instructor personnel costs are shown in table 10. Since both FASO and VP-31 at differing times provide instructors to the LC depending on student progress in the MCS, it was assumed that a full time instructor man-year equivalent was required in the LC for each track. The assumed instructor rank/rate is also shown. Koehler (15, 16) again are the billet cost references.

### Learning Center Cost Summary

Table 11 shows the total cost of the LC for each crew position accounting for both noninstructor (NI) and instructor costs per student.

TABLE 10

LEARNING CENTER INSTRUCTOR PERSONNEL COSTS

| Crew Position | Instructor Rank/Rate | Instructor Cost Per Year | Students Per Year | Cost Per Student |
|---|---|---|---|---|
| Pilot | LT | $75,347 | 180 | $419 |
| NFO | LT | 29,189 | 120 | 243 |
| FE | E-6 | 28,034 | 140 | 200 |
| SS 1/2 | E-6 | 23,138 | 120 | 193 |
| SS 3 | E-5 | 18,662 | 60 | 311 |
| Comm | E-5 | 23,622 | 120 | 197 |
| ORD | E-5 | 18,602 | 40 | 465 |
| | | Total | 780 | |

TABLE 11

TOTAL LEARNING CENTER COSTS PER STUDENT
AVERAGED OVER ALL STUDENTS, ALL TRACKS

| Crew Position | Noninstructor | Instructor Cost | Total |
|---|---|---|---|
| Pilot | $418 | $419 | $837 |
| NFO | 418 | 243 | 661 |
| FE | 418 | 200 | 618 |
| SS 1/2 | 418 | 193 | 611 |
| SS 3 | 418 | 311 | 729 |
| Radio | 418 | 197 | 615 |
| ORD | 418 | 465 | 883 |

NOTE:

Costs per hour can be found by dividing the total LC cost by the number of hours in the MCS, i.e., for pilot LC hours total 248; cost $837, therefore cost is $3.38 per hour.

#### Training Device Costs

Training device costs have two major components, acquisition costs and operating costs. Allbee and Semple (5) discuss in their model an elaborate means for estimating these costs in an Air Force setting. Orlansky and String (3) take a somewhat simpler view of arriving at the same costs. Browning, et. al., (6) estimates the cost for only the training devices required for pilot training. This model, then, is an elaboration of the Orlansky and String model.

Training Device Acquisition Costs. Table 12 shows the training device acquisition costs. The unit prices were obtained from the Chief of Naval Education and Training (CNET), directory of Naval Training Devices (21). The unit price was amortized over 15 years to calculate the price per year. Fifteen years of service life for a device is assumed. It should be noted, however, that the unit price reflected in the CNET report is probably low in that it does not reflect costs from trainer engineering changes and costs from changes or modifications to the P-3. The operating hours were reported by FASOTRAGRUPAC to the NALCOMIS reporting system. The yearly operating hours authorized were then divided into the acquisition cost per year in order to calculate the acquisition cost per hour.

TABLE 12

TRAINING DEVICE ACQUISITION COSTS
AT NAS MOFFETT FIELD, CA

| Trainer | Unit Price | Price Per Year If Amortized 15 Years | FASO Operating Hours | Acquisition Cost Per Hour Per Year |
|---|---|---|---|---|
| 2F87 (F)* | $4,278,760 | $285,250 | 8756 | $65.16 |
| 2F87 (T)* | 4,646,882 | 309,792 | 8023 | 77.22 |
| 14B40 | 2,081,970 | 138,798 | 1512 | 91.80 |
| 14B44 | 2,764,113 | 184,274 | 2526 | 72.95 |
| 2C45A | 1,232,740 | 82,183 | 1423 | 57.75 |
| 2F69E | 4,270,000 | 284,667 | 3139 | 90.69 |

*Two devices at Moffett.

NOTE: Certain obsolete devices were deleted from this table due to insufficient data being available, e.g., 15 Z 1.

TABLE 13

FASOTRAGRUPAC REPORTED OPERATING COSTS

| Trainers | FY79 Costs | Authorized Operating Hours | Operating Costs Per Hour |
|---|---|---|---|
| 2F87 (F) | $326,083 | 8,756 | $ 37 |
| 2F87 (T) | 277,608 | 8,023 | 35 |
| 14B40 | 89,607 | 1,512 | 60 |
| 14B44 | 98,323 | 2,526 | 39 |
| 2C45A | 57,078 | 1,423 | 40 |
| 2F69E | 321,311 | 3,139 | 102 |

### Operating Costs

Table 13 depicts the FASOTRAGRUPAC FY 1979 reported operating costs per device (19).

### Training Device Cost Summary

Table 14 shows a summary of the annual operating and acquisition costs per device per year from tables 12 and 13.

Although the annual cost per device represents a significant cost in this model, the cost per student hour must be considered. An assumption is made that there is no slack variable, that is, when a student seat is available for assignment it will be filled. If this assumption is used, then the cost per seat in the model can be found by adding the acquisition cost per hour (table 12) and operating cost per hour (table 13) to obtain this total cost per hour per seat. Then, the number of seats per device are divided into the cost per hour to obtain cost per student hour per seat (table 15). If a seat is available for scheduling but not used, it creates a negative cost to the model, adding to the real cost. The actual student usage might only be 80 percent of the authorized operating hours. If this is so, it raises the true cost of a student hour. In order to make this model as workable as possible, the simplifying assumption is made to ignore this factor.

TABLE 14

TOTAL TRAINING DEVICE OPERATING AND ACQUISITION COST PER YEAR PER DEVICE

| # Trainer | Yearly Amortized Acquisition Cost | FY 79 Operation & Maintenance Cost | Yearly Costs |
|---|---|---|---|
| (2)2F87 (F) | $570,500 | $326,083 | $896,583 |
| (2)2F87 (T) | 619,584 | 277,608 | 897,192 |
| (1)14B40 | 138,798 | 89,607 | 228,405 |
| (1)14B44 | 184,274 | 98,323 | 282,597 |
| (1)2C45A | 82,183 | 57,018 | 139,261 |
| (1)2F69E | 284,667 | 321,311 | 605,978 |

TABLE 15

TRAINING DEVICE COST PER STUDENT SEAT HOUR

| Trainer | Acquisition Cost Per Hour | Operating Cost Per Hour | Total Cost Per Hour | Total Number Student Seats | Cost Per Student Hour |
|---|---|---|---|---|---|
| 2F87F | $65 | $ 37 | $102 | 3 | $34 |
| 2F87T | 77 | 35 | 112 | 5 | 22 |
| 14B40 | 92 | 60 | 152 | 3 | 51 |
| 14B44 | 73 | 39 | 112 | 6 | 19 |
| 2C45A | 58 | 40 | 98 | 3 | 33 |
| 2F69E | 81 | 102 | 200 | 8 | 25 |

Instructor cost for each instructional medium, table 16, was obtained by using the billet costs from Koehler (15) for enlisted billet costs and Koehler (16) for the officer billet costs. The rate/rank of the instructors are shown in the assumptions. The proportional cost of each instructor to each medium was taken from table 3. The following assumptions were used in the development of table 16.

1. Pilot instructor is an O-3
2. NFO instructor is an O-3
3. FE instructor is an E-6 AD
4. SS 1/2 instructor is an E-6 AW
5. SS 3 instructor is an E-5 AW
6. COMM instructor is an E-5 AT
7. ORD instructor is an E-5 AO
8. 2,000 hours per instructor man year

Aircraft Flight/Lab Costs

The cost per hour for the P-3C aircraft was determined from the NALCOMIS report (13). First, the total annual flying hours for the P-3C aircraft for 1979 was determined to be 104,863. Then the total aircraft support cost, less petroleum oil and lubricants (POL) and training support was obtained. This cost is $155,257,000. Annual flight hours were divided into aircraft support costs, resulting in a figure for cost per hour without POL, which equates to the cost of a lab aircraft, of $1,480 per hour. The COMNAVAIRPAC (22) reported cost per flight hour for POL is $951. The cost per flight hour is therefore $2431. As indicated before in the assumptions, aircraft depreciation has not been factored into the costs.

TABLE 16

INSTRUCTOR COST PER HOUR FOR INSTRUCTIONAL MEDIA (in $)

| | OFT/PT | WST/Aircraft Lab | P-3 Flight |
|---|---|---|---|
| 1. Pilot | 18 | 18 | 37 |
| 2. NFO | 15 | 15 | 15 |
| 3. FE | 7 | 7 | 7 |
| 4. SS 1/2 | 3 | 6 | 6 |
| 5. SS 3 | 5 | 9 | 5 |
| 6. COMM | -- | -- | 6 |
| 7. ORD | -- | 3 | 5 |

As described earlier, the pilot and flight engineer accrue half of the aircraft cost per hour during Phase B of the MCS, since they are the only two crew student positions who log flight hours during that Phase. During Phases C and D, seven crew student positions are filled. For each flight hour, the cost is distributed across all crew positions.

RESULTS

Cost Summaries for P-3 Training Curriculum

Table 17 displays the cost per hour for each instructional medium for each crew position. The cost for each training device hour was obtained by adding the training device cost per student hour (found in table 15) to the VP-31 instructor cost per hour, for training devices, aircraft lab and aircraft hours (from Table 16).

Table 18 shows the total cost for each crew position. The ISD costs were obtained from table 8 and the learning center (LC) costs from table 11.

The cost for each medium was calculated by multiplying the costs per hour (table 17) by the number of hours each student utilized a media displayed in the master course syllabus (table 2).

Billet costs were determined by that proportion their scheduled MCS training time is of a man-year. An average student rank/rate was used. For example, a first tour pilot is probably a ENS, he takes 100 working days to complete the syllabus. This is about 42 percent of a man-year. Koehler was referenced for annual billet costs (15, 16).

The costs to train a typical P-3 crew have been summarized from Table 18 and are displayed as Table 19.

TABLE 17

COST PER HOUR PER MEDIUM PER CREW POSITION
(in $)

| | 2C-45/ 2F69 | 2F87F | 14B44 | 2F87T | P-3 MCS Phase B | P-3 Phase C,D |
|---|---|---|---|---|---|---|
| Pilot | | | | | | |
| 1st Tour (B or C) | 51 | 52 | 37 | 40 | 1252 | 384 |
| 2nd Tour (B or C) | 51 | 52 | -- | 40 | 1252 | 384 |

| | 2C-45/ 2F69 | 2F87F | 2F87T | Static A/C | P-3 | |
|---|---|---|---|---|---|---|
| FE (B or C) | 40 | 41 | 29 | UNK* | 1222 | 354 |

| | A/C LAB | 2F69 | 2F87T | P-3 |
|---|---|---|---|---|
| NFO B (1st Tour) | 755 | 40 | -- | 362 |
| C (1st Tour) | 755 | -- | 37 | 362 |

| | 14B44 | 2F69 | 2F87T | A/C LAB | P-3 |
|---|---|---|---|---|---|
| SS 1/2 B | 22 | 31 | -- | 746 | 353 |
| C | 22 | -- | 28 | 746 | 353 |

| | 14B40 | 2F69 | 2F87T | A/C LAB | P-3 |
|---|---|---|---|---|---|
| SS 3 B | -- | 34 | -- | 749 | 353 |
| C | 56 | -- | 31 | 749 | 353 |

| | A/C LAB | P-3 |
|---|---|---|
| ORD B | 496 | 352 |
| C | 496 | 352 |

| | A/C LAB | P-3 |
|---|---|---|
| COM, B | 745 | 352 |

NOTE:
* Static A/C are assumed to have no cost since they do not have power and can be any A/C not in use on the flight line.

TABLE 18

COST PER CREW POSITION
(in $)

CREW POSITION

| Pilot | ISD | LC | 2C45/ 2F69 | 2F87F | 14B44 | 2F87T | P-3 |
|---|---|---|---|---|---|---|---|
| 1st Tour (ENS) | 653 | 837 | 1122 | 1456 | 111 | 1280 | 51980 |
| 2nd Tour (LCDR) | 653 | 837 | 459 | 1560 | NA | 1280 | 32254 |

| Billet Costs | TOTAL |
|---|---|
| 14,389 | $71,828 |
| 29,215 | $66,257 |

TABLE 18 (Continued)

COST PER CREW POSITION
(in $)

| FE | ISD | LC | 2C45/ 2F69 | 2F87F | P-3 |
|---|---|---|---|---|---|
| (AD-3) | 355 | 618 | 320 | 1476 | 71536 |

| Billet Costs | TOTAL |
|---|---|
| 6,511 | $80,816 |

| | ISD | LC | A/C LAB | 2F69 | 2F87 | P-3 |
|---|---|---|---|---|---|---|
| NFO B (ENS) | 866 | 661 | 15855 | 2760 | -- | 25340 |
| C (ENS) | 866 | 661 | 20385 | -- | 2738 | 19548 |

| Billet Costs | TOTAL |
|---|---|
| 11,375 | $56,857 |
| 11,375 | $54,573 |

| | ISD | LC | 14B44 | 2F69 | 2F87T | A/C LAB |
|---|---|---|---|---|---|---|
| SS 1/2 B (AW-3) | 603 | 611 | 1254 | 952 | -- | 14920 |
| C (AW-3) | 603 | 611 | 1188 | -- | 896 | 26110 |

| P-3 | Billet Costs | TOTAL |
|---|---|---|
| 12708 | 6411 | $37,499 |
| 10590 | 6411 | $46,409 |

| | ISD | LC | 14B40 | 2F69 | 2F87T |
|---|---|---|---|---|---|
| SS 3 B (AW-3) | 753 | 729 | -- | 1088 | -- |
| C (AW-3) | 753 | 729 | 2016 | -- | 992 |

| 15Z1/15E16 | A/C LAB | P-3 | Billet Costs | TOTAL |
|---|---|---|---|---|
| 2016 * | 19474 | 24710 | 4856 | 53626 |
| -- | 18725 | 24710 | 4856 | 52781 |

* (Device 15Z1 is obsolescent, costs are not identified in COG-20 index, device 14B40 costs were therefore assumed.)

| | ISD | LC | A/C LAB | P-3 | Billet Costs | TOTAL |
|---|---|---|---|---|---|---|
| ORD B (AO-3) | 188 | 883 | 18848 | 8448 | 2063 | 30430 |
| C (AO-3) | 188 | 883 | 14800 | 8448 | 2063 | 26382 |

(A/C LAB for B assumes 2 students per class, C four students per class.)

| | ISD | LC | A/C LAB | P-3 | Billet Costs | TOTAL |
|---|---|---|---|---|---|---|
| COM B (AT-3) | 1017 | 615 | 37995 | 10560 | 8238 | 58425 |

(A/C LAB assumes two students.)

TABLE 19

FRS TRAINING COSTS FOR A P-3C CREW

| | | | |
|---|---|---|---|
| Pilot | 2nd Tour | | $ 66,257 |
| | 1st Tour | | 71,828 |
| Flight Engineer | | | 80,816 |
| Naval Flight Officer | | 2 @ 54,573 | 109,146 |
| Sensor Stations, 1 & 2 | | 2 @ 46,409 | 92,818 |
| Sensor Station, 3 | | | 52,781 |
| Ordinance Man | | | 26,382 |
| | | Total | $500,028 |

DISCUSSION

A summary of the percentages that the various components, ISD, learning center, training devices, aircraft, and student billet costs represent along with their approximate costs are depicted below. Table 19, which arrays the data, has been compiled from approximate costs to train a P-3C crew, about $500,000. Table 18 arrays the cost for each component by crew position.

| Component | $ Cost | Percentage of Cost |
|---|---|---|
| ISD | 5,540 | 1.1 |
| LC | 6,448 | 1.2 |
| Training Devices | 21,716 | 4.3 |
| P-3C Total | 375,719 | 75 |
| (Lab Only) | (126,515) | (25) |
| (Flight) | (249,204) | (50) |
| Billet Cost | 92,606 | 18.5 |
| Approx. | $500,000 | |

The cost for ISD-related activities when considered in the total costs to train a P-3C crew is, when viewed in the total P-3 program, minor. Even though their possible impact on overall costs are significant. This is, in part, a reflection of spreading the ISD costs across the probable life cycle of the weapons system. The learning center costs are also minor when viewed in the total crew training costs, about 1.2 percent. Training devices also only represent 4.3 percent of the total training costs, this was a surprising finding in view of their initial acquisition costs. The P-3 aircraft costs as related to the crew training costs are the major contributors. The total P-3 costs represent 75 percent of the cost to train a P-3C crew. The flight-hour costs represent 50 percent of the total crew costs and the use of the P-3 aircraft as a lab represents 25 percent.

A model specifically tailored for collection of data in order to support decision making in fleet replacement squadrons seems to be warranted, in that the data to support such a model is existing and can be used, if correctly applied, for decision making. It should also be noted that this report only covers the cost side of a possible cost benefit model. The benefit assumptions also should be considered in a total system model.

The costs for the P-3 when used as an aircraft lab are extremely high and contribute about 25 percent of the cost to train a crew. The cost impact of A/C lab is significant in the NFO, SS 1/2, SS-3, ORD, and CON B crew positions. A cost analysis appears to be warranted in order to support decisions regarding the acquisition of supplemental training devices. (For example, if the P-3 Lab were to be used by the P-3C NFO for harpoon missile training due to a paucity of realism in the training device, application of a cost model might support acquisition of a requisite device.)

The fine tuning of the training support requirements for a major weapons system is a complex process. The costs involved are not clear to Navy planners since they cross budgetary lines of control. A model such as this can assist the planners in a fleet training location to help estimate the relative impact on the total training cost that are reflected by component cost changes.

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# A TOTAL TRAINING SYSTEM COST EFFECTIVENESS MODEL

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## ABSTRACT

Rapidly increasing costs, and military requirements now dictate a total system life cycle approach to training system design and development. Quantitative evaluation of training system concepts and acquisition alternatives requires the use of a rational procedure or model which defines the relationships between all elements of the system. A first generation training system cost effectiveness (TSCE) model has been developed which allows media designers, instructional psychologists, and system analysts to integrate their concepts on a total system life cycle basis. This model uses the Instructional System Development (ISD) process to derive media mix and syllabus. Terminal learning objectives (TLOs) and syllabus are linked to design-oriented media characteristics and performance. Application of the TSCE model to undergraduate pilot training system concept evaluation provides a detailed understanding of how the major system variables interact in addition to quantitative definition of total system performance.

## BACKGROUND

This paper presents preliminary results of an on-going research task at the North American Aircraft Division, dealing with the definition and application of a Training System Cost Effectiveness (TSCE) Model for evaluation of undergraduate pilot training system concepts.

The continuing objective of this task has been to model the entire Navy strike training system and use the TSCE model to evaluate system alternatives. The training system includes a curriculum, training media (aircraft, simulators, academic materials), an integrated support system (facilities, equipment, personnel, consumables), and a training management system.

Navy strike training is presently taught in two phases (intermediate and advanced) which require a total of 220 training days as shown below in Figure 1. The Student Naval Aviator (SNA) is awarded an Ensign's commission at the end of Aviation Officer Candidate Training (AOCT). The SNA must then complete primary flight training in T-34C aircraft before entering intermediate strike training in Rockwell T-2C aircraft. Wings are awarded on completion of advanced strike training in TA-4J aircraft followed by transition to operational aircraft in Fleet Replacement Squadrons

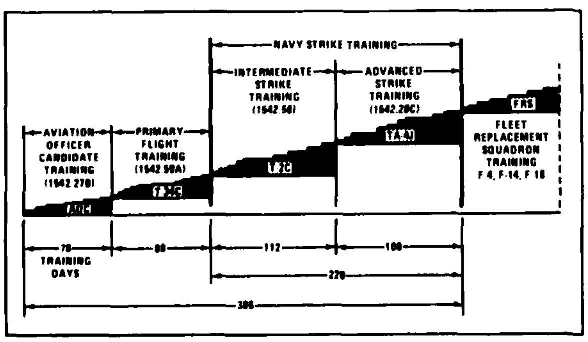


Figure 1 Navy Strike Flight Training

(FRS). The present curricula designations are shown in Figure 1 as CNATRAINST 1542.27B, .59A, .56, and .20C from Ref. (1), (2), (3), and (4), respectively.

Although the TSCE model has been developed for evaluation of various Navy strike pilot (Intermediate + Advanced) training system concepts, the same general procedures are also applicable to Navy Primary and FRS phases as well as most other flight training systems.

Review of the literature, discussion with recognized experts, and analysis of existing models indicated in April 1979 that no generally accepted model or procedure existed for evaluation of the entire training system. Additional research provided the following insights:

1. All training system designs should start with an analysis of the operational tasks to be performed by the trained individual. Certain of these tasks are selected as tasks to be trained and training objectives or requirements should be defined before system design is initiated.

2. Recent advances in the application of instructional psychology and modern instructional technology have prompted the definition of a systematic design procedure for instructional systems called ISD which begins as described in item 1. above. When the Instructional System Development (ISD) process is used, a direct link is established between training objectives, media mix, and curriculum.

3. Existing versions of the ISD process define hands-on (aircraft, and simulator) media requirements and capabilities in general terms which do not provide adequate guidance for media design.

4. It became clear that computer processing of data associated with the ISD and other TSCE submodels would be necessary in order to drastically reduce iteration time and increase responsiveness of the entire TSCE model to the training system design process.

5. The design of pilot training systems is still partially an art due to the complexities and psychological subtleties of some training system variables. Since relevant experimental or analytic data are sparse, training system analysis and design are still highly dependent on extrapolations from historical data and statistically analyzed expert opinion.

## THE TSCE MODEL

The TSCE model has been organized into five basic modules as shown in Figure 2. Each module contains one or more submodels. The Input Module includes all system requirements, criteria, and guidelines initially defined, such as:

- Existing Assets (Facilities, Media, Equipment)
- Training Policies and Doctrine
- Terminal Learning Objectives (TLOs)
- Pilot Training Rate (PTR)
- System Life and IOC
- Student and Aircraft Attrition Data
- Existing Curriculum
- Media Characteristics Data
- Organization and Basing
- Personnel Data and Costs
- Training Management System (TMS) Functions and Configuration

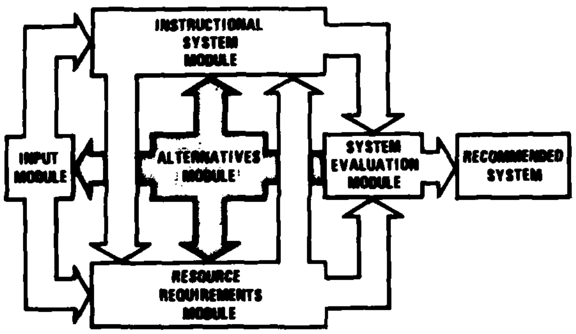


Figure 2 Organization of the TSCE Model

The above listing is representative but not exhaustive. The Input Module also contains initial media design concepts and integrated logistic support (ILS) concepts to be evaluated.

The Instructional System Module includes the ISD submodel, ASSEM (Aircraft/Simulator Syllabus Extrapolation Model), and the TMS submodel as shown in Figure 3. Terminal Learning Objectives (TLOs) are decomposed in the ISD submodel to a hierarchy of enabling objectives (EOs) by a subject matter expert (SME)/instructional psychologist (IP) team. This process establishes the master sequence of instruction. All EOs are stated in behavioral terms on objective/media worksheets along with their associated conditions and standards, and classified as academic or hands-on (simulator, aircraft) objectives. The same SME/IP team then establishes media requirements for each EO by selecting those media attributes which assure effective training and efficient instruction. The media attributes list for academic EOs is shown in Figure 4 and the hands-on attributes are shown in Figure 5. The hands-on attributes contain an equipment list

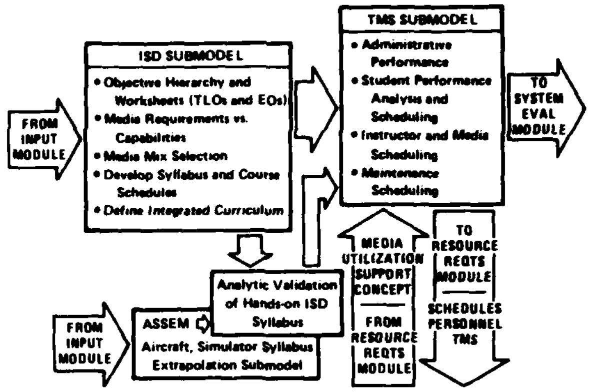


Figure 3 Instructional System Module

which is relevant to aircraft or simulators, an aircraft characteristics list organized in discrete performance levels, and a simulator characteristics list which includes most of the critical design criteria for student and instructor stations. These attribute lists must be defined with care. In particular, the hands-on attributes should be design-oriented and sufficiently discriminating to represent significant differences in training effectiveness and cost of media design concepts. A particular EO may require visual cues for effective training but the characteristics (field of view, B&W or color, night/dusk or daylight) and sophistication of those visual cues should also be addressed, depending on the EO. At this stage in the ISD submodel, insertion of design-oriented attributes improves the media selection process as long as selection of alternatives can be resolved and decisions are not inhibited. Training objectives must be linked with principal design attributes of the media in this manner before changes in media can be traced to changes in curriculum, media quantities, and system life cycle cost.

| |
|---|
| DISPLAY |
| AUDIO-VOICE |
| AUDIO |
| TACTILE |
| KINESTHETIC |
| VISUAL |
| Verb/Text |
| Pictorial |
| Diagrams/Drawings |
| Spatial Layout |
| Motion |
| Color |
| RESPONSE |
| VERBAL/WRITTEN |
| P.T.M. |
| MANIPULATE |
| EVALUATION |
| INSTRUCTOR |
| AUTOMATED |
| PEER |
| STDNT. SCORED WITH KEY |

| |
|---|
| FEEDBACK |
| FREQUENCY |
| Immed/Response |
| Immed/Error |
| Periodic |
| Post-Session |
| CONTENT |
| Correct Answer |
| Right/Wrong Elaborated |
| Branch to New Display |
| SPECIAL REQS |
| CREW/TEAM INT |
| ENVIRONMENT |
| MOTION |
| TIME VARIABILITY |
| LEARNER CONTROL |

Figure 4 Academic Media Attributes

| EQUIPMENT | |
|---|---|
| ENGINE | |
| AIRCRAFT FUEL SYSTEM | |
| ELECTRICAL POWER SYSTEM | |
| HYDRAULIC POWER SUPPLY | |
| EMERGENCY POWER UNIT | |
| ESCAPE SYSTEM | |
| AIR CONDITIONING AND PRESSURIZATION | |
| OXYGEN | |
| LANDING GEAR | |
| NOSE WHEEL STEERING | |
| WHEEL BRAKE | |
| SPEED BRAKE | |
| TAIL HOOK | |
| CATAPULT LAUNCH ASSEMBLY | |
| WING FLAP | |
| LIGHTING (INTERNAL) | |
| LIGHTING (EXTERNAL) | |
| FLIGHT CONTROL | |
| AUTOPILOT | |
| FLIGHT GEAR | |
| MARKER BEACON | |
| IFF/SIF | |
| TACAN | |
| ILS | |
| ADF | |
| AHRS (ATTITUDE HEADING REFERENCE SYSTEM) | |
| ACLS | |
| INTERCOM | |
| VHF/UHF | |
| PITOT STATIC TUBES | |
| FLIGHT INSTRUMENTS | |
| RADAR ALTIMETER | |
| ADI (ATTITUDE DIRECTOR IND.) | |
| HSI (HORIZONTAL SITUATION IND.) | |
| HUD (HEADS-UP DISPLAY) | |
| INERTIAL NAVIGATION SET | |
| RADAR DISPLAY | |
| GUN, FULL SCALE, OPERATING | |
| STORES MANAGEMENT | |
| WEAPONS | |
| WEAPONS CONTROL | |
| ELECTRONIC WARFARE EQUIPMENT | |
| IN-FLIGHT INSTRUCTIONAL AIDS | ■ |
| HUD CAMERA | |
| STUDENT PERFORMANCE AUTOMATIC MONITORING (SPAM) | |
| VIDEO RECORDING | |
| ELECTRONIC WARFARE SIMULATION | |
| RADAR SIMULATION | |
| NAVIGATION SIMULATION | |
| GUN SIMULATION | |

| SIMULATOR CHARACTERISTICS | | | | |
|---|---|---|---|---|
| STUDENT STATION | | COCKPIT FIDELITY | PHOTO REPLICA, ACTUAL SIZE/POSITION INSTRUMENT PANEL/CONSOLES | |
| | | | STATIC 3-D REPLICA WITH MOVING CONTROLS. PROPER TRAVEL/DYNAMIC FEEL | |
| | | | 3-D REPLICA WITH SELECTED FUNCTIONING CONTROLS/DISPLAYS/SYSTEMS (PTT) | |
| | | | ALL CONTROLS/DISPLAYS/SYSTEMS FUNCTIONING LIKE AIRCRAFT (OFT) | |
| | | DYNAMICS (MODELING) | FUNCTIONING NAVIGATIONAL INSTRUMENTS WITH GEOGRAPHIC POSITION READOUTS | |
| | | | EXTERNAL INFLUENCE (WIND, TURBULENCE, ETC.) | |
| | | ACOUSTICS | AIRCRAFT SYSTEMS, ENGINE, ETC | |
| | | | AERODYNAMIC | |
| | | MOTION CUES | FLIGHT INSTRUMENTS | |
| | | | MOTION BASE | |
| | | | G-SUIT | |
| | | | G-SEAT | ■ |
| | | | • SUSTAINED G'S ONLY | |
| | | | • SUSTAINED G'S/BUFFET | |
| | | | EXTERNAL VISUALS | |
| | VISUAL | FIELD OF VIEW | STRAIGHT AHEAD (45° AZ, 30° EL) | |
| | | | LIMITED PERIPHERAL (135° AZ, 30° EL) | |
| | | | PERIPHERAL (180° AZ. 30° EL) | |
| | | | LIKE AIRCRAFT (320° AZ, −60° to 120° EL) | |
| | | BRIGHTNESS/ COLOR | NIGHT/DUSK | |
| | | | DAY (BLACK AND WHITE) | |
| | | | DAY (COLOR) | |
| | | SCENE DETAILS (GENERAL) | TERRAIN TEXTURE AND HORIZON | |
| | | | PLUS CV OR RUNWAY/AIRPORT ENVIRONMENT | |
| | | | PLUS SOME GEOGRAPHIC/CULTURAL FEATURES FOR SPECIFIC LOCATIONS | |
| | | | PLUS REALISTIC GEOGRAPHIC/CULTURAL FEATURES WITH 3-D OBJECTS | |
| | | SYSTEM FEATURES | WEATHER PROGRAMMING (THUNDERSTORMS, ETC) | |
| | | | FUNCTIONING AIRPORT LIGHTING SYSTEM (VASI, ETC) | |
| | | | PROGRAMMABLE SCENES (DUPLICATING DIFFERENT LOCATIONS) | |
| | | | MOVING VEHICLES ON SCENE | ■ |
| | | | • AIR | |
| | | | • GROUND | |
| INSTRUCTOR STATION | | CONTROL FEATURES | MALFUNCTION INSERTION (EMERGENCY, PROBLEMS) | |
| | | | STOP-ACTION | |
| | | | RESET | ■ |
| | | | • TO ONE POSITION | |
| | | | • TO ANY POSITION | |
| | | | PLAYBACK | |
| | | | COMMUNICATIONS | ■ |
| | | | • INSTRUCTOR/STUDENT ONLY | |
| | | | • REALISTIC COMM. ENVIRONMENT | |
| | | | FLIGHT DEMO/PLAYBACK CAPABILITY | |
| | | | INSTRUCTOR POINTING CAPABILITY ON VISUAL SCENE | |
| | | | INSERTION OF TARGETS/THREATS ON VISUAL SCENE | |

| AIRCRAFT CHARACTERISTICS | | | |
|---|---|---|---|
| MANEUVERABILITY | INSTANTANEOUS LOAD FACTOR ("G'S") | 7–8 | |
| | | 6–7 | |
| | | 5–6 | |
| | | 4–5 | |
| | SUSTAINED LOAD FACTOR ("G'S") | 5–6 | |
| | | 4–5 | |
| | | 3–4 | |
| | | 2–3 | |
| | ROLL ACCELERATION BANK ANGLE (DEGREES IN 1ST SECOND) | 70–90 | |
| | | 50–70 | |
| | | 30–50 | |
| | | 10–30 | |
| SERVICE CEILING (THOUSANDS OF FEET) | | 50 | |
| | | 40 | |
| | | 30 | |
| | | 20 | |
| SPEED REGIME | MAXIMUM LEVEL FLIGHT SPEED AT SEA LEVEL (MACH) | 0.9–1.2 | |
| | | 0.8–0.9 | |
| | | 0.7–0.8 | |
| | | 0.6–0.7 | |
| | LANDING APPROACH SPEED (KNOTS) | 120–130 | |
| | | 110–120 | |
| | | 100–110 | |
| | | 90–100 | |
| RATE OF CLIMB AT SEA LEVEL (THOUSANDS OF FT/MIN) | | 8.5–10.0 | |
| | | 7.0–8.5 | |
| | | 5.5–7.0 | |
| | | 4.0–5.5 | |
| FLYING QUALITIES | GUST RESPONSE | HIGH | |
| | | MEDIUM | |
| | | LOW | |
| | VERTICAL RESPONSE TO THROTTLE IN POWER APPROACH | HIGH (F-4, A-4) | |
| | | MEDIUM | |
| | | LOW (T-2, S-3) | |

Figure 5 Hands-On Media Attributes

## Media Selection

The initial step of media selection within the ISD submodel, occurs when media requirements from the objective/media worksheets are compared with media capabilities for each EO in the objective hierarchy. Media capabilities are defined in matrix format (attributes versus media candidates) using the same list of media attributes shown in Figures 4 and 5. A team of SMEs, IPs, and instructional technologists (ITs) rate all candidate media against the attributes with a value scale. *Comparison of media requirements* with media capabilities allows the media to be scored for each EO. Only those media which meet all requirements to some degree, are considered acceptable for each EO. Those candidates not meeting all requirements are dropped for that EO. Media requirements for all EOs are processed in this manner and acceptable media are then ranked according to the number of EOs satisfied. These acceptable media are then considered in combinations of 2, 3, 4....n at a time and ranked, in terms of EOs satisfied by media mix. Those media mixes which satisfy all EOs are then evaluated in terms of relative life cycle cost using preliminary estimates of media quantities, and a media mix selection is made. Hands-on EOs associated with the selected media mix are then listed by training medium and preliminary DPE (demonstration, practice, evaluation) time increments are assigned to each of the media in the mix, by EO. The selected media mix, identification of EOs by medium, assignment of time increments by EO/media combination, and sequence of instruction from the objective hierarchy provide the principal input data for development of a training syllabus. All of these data generated in the ISD submodel are loaded, when available, into a computerized data base which facilitates each successive stage of synthesis.

## Curriculum Development

Syllabus/Curriculum development begins with computer interactive sequencing of all hands-on objectives and assignment of a master sequence number code. Academic objectives are then grouped as prerequisites to hands-on objectives where applicable, assigned a sequence number, and further grouped into lessons. A preliminary syllabus is available at this stage which includes a media hours summary, instructional sequence, and lesson groupings. The syllabus is then expanded to a curriculum with the development of training module schedules and total contact time data. A final computer interactive inspection and edit is completed prior to printout of the integrated curriculum.

## Curriculum Validation

Since the curriculum influences most aspects of training system design including system effectiveness and life cycle cost, validation of the curriculum is initiated as soon as a preliminary syllabus (distilled curriculum) is available, and proceeds in parallel with training system design and implementation until total validation has been completed. Validation examines correspondence of the ISD-generated curriculum and its components to perceived reality in accordance with the three steps listed below:

1. Theoretical validity (assessed prior to training system design)

- Theory underlying the ISD process.
- Assumptions (stated or implied)
- Transition from perceived reality to the ISD submodel used.

2. Data validity (assessed during training system design)

- Accuracy, completeness, impartiality, and appropriateness of the original input data.
- How the ISD submodel deals with transformation of the original input data.

3. Operational validity (assessed during training system operation)

- Divergence between the ISD-generated curriculum and the curriculum which evolves from training system operation.

The initial step in this validation process takes place within the TSCE model. Starting with essentially the same inputs and in parallel with the ISD submodel, a second (non-ISD) syllabus is derived by extrapolation from the existing training command syllabus using the Aircraft/Simulator Syllabus Extrapolation Model (ASSEM) shown in Figure 6. Comparison of the ASSEM-derived hands-on syllabus with the ISD-derived hands-on syllabus provides an initial check on the media hours by training stage listed in the ISD syllabus.

The ASSEM process was developed from concepts published in Ref. [5] and includes the seven basic steps listed below:

- Since syllabus extrapolation in ASSEM is based on the weighted application of performances differences between media of the same type, syllabus differences, due to other effects such as non-equivalence of TLOs and media types must be eliminated prior to syllabus extrapolation. The initial step is therefore to define common and/or equivalent TLOs between the existing and candidate syllabi as shown in Figure 6.

- Organization of common TLOs and associated media hours by training mission or stage (completed by SME/IP team).

- Derivation of simulator/aircraft training transfer factors for specific media/mission combinations (from existing data and by SME team).

- Define total hands-on hours in terms of one training medium (so that syllabi can be compared) by using training transfer factors to convert all simulator hours to aircraft hours (or the converse for simulator syllabus extrapolation).

- Derive weighting factors for each media characteristic/training mission combination using SME team.

- Derive training rate factors (TRFs) for each of the candidate medium performance characteristics and ratio to the TRF for the existing or baseline medium.

- Run the ASSEM computer program which calculates the product in matrix format of

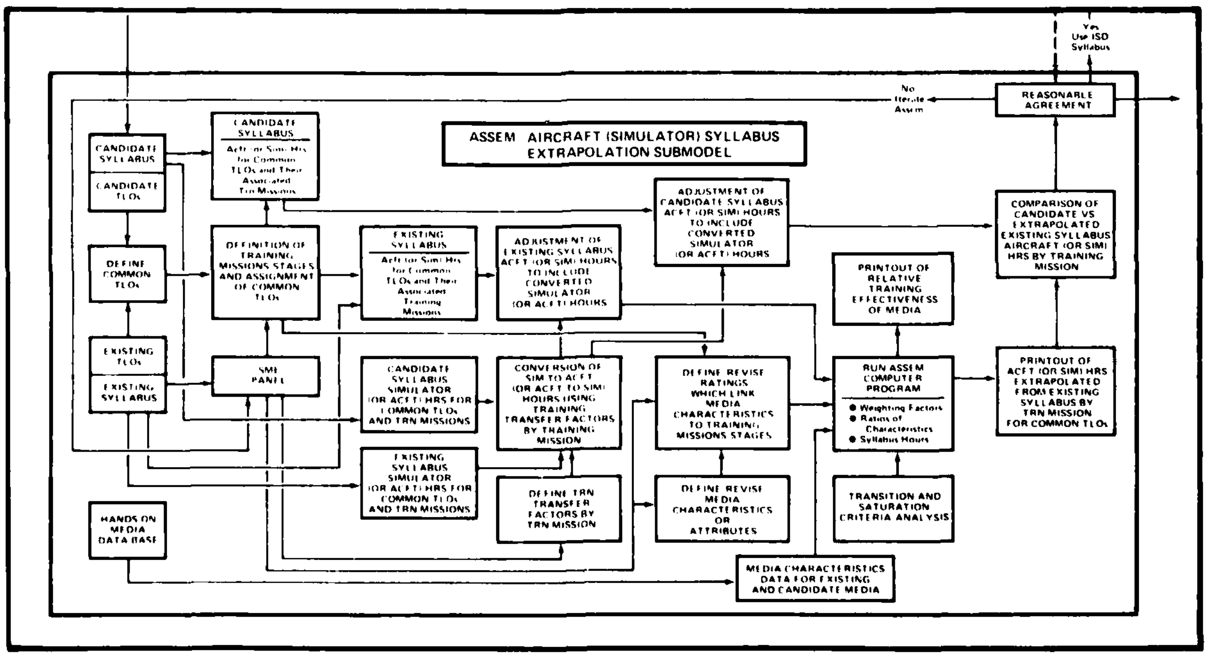


**Figure 6 Aircraft/Simulator Syllabus Extrapolation Model**

weighting factor, TRF ratio, and existing syllabus hands-on hours by training mission to yield extraplated syllabus hands-on hours. This extrapolated hands-on syllabus is then compared with the candidate or ISD-generated syllabus as shown in Figure 6.

The ASSEM submodel is based on the following three assumptions:

1. The skill level attained by a student aviator is a function of training time as defined in Figure 7.

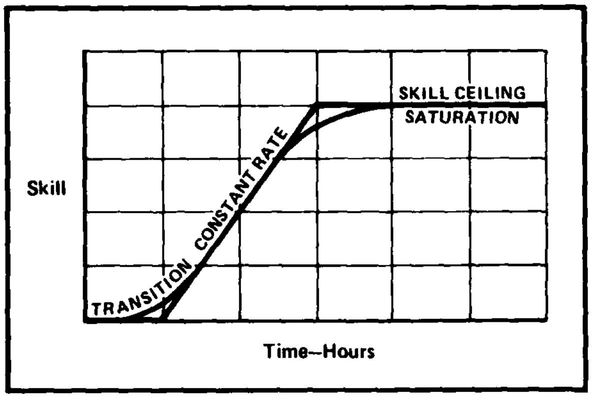


Figure 7 Learning Curve

2. The relationship between media design characteristics (sustained load factor, field of view, etc.) and training mission/stages (familiarization, basic instruments, etc.) can be adequately quantified by a team of expert aviators and statistically analyzed to provide weighting factors.

3. Syllabus media hours are inversely proportional to media characteristics where the proportionality is assumed to be linear, except in those cases where the team of experts establish a different relationship.

The curve in Figure 7 can be approximated by three linear segments. The two horizontal segments represent transition and saturation, respectively, and the linear segment connecting them represents a constant learning rate. During the initial or transition portion of the curve, skill level is not increased significantly even though training time is expended for general familiarzation (getting confortable) with the aircraft or simulator. ASSEM uses a statistical relationship for calculation of transition time.

Derivation of the media characteristic versus training mission weighting factors has been completed by a team of expert aviators which included Navy trained test pilots, an Air Force fighter/attack pilot, aeronautical engineers with civilian piloting experience, and an educational psychologist with instructor pilot, simulator development, and human factors experience. The mean values of individual scores for aircraft are recorded in matrix format as shown in Figure 8. The same type of matrix has been defined for simulators. Weighting factors have been developed from these means which quantified the team's evaluation of the relative importance of each performance characteristics. For each mission, the sum of the weighting factors is 1.0.

Existing syllabus hours, the weighting factors described above, and training rate factors described previously are the three types of data used in the ASSEM computer program. Training rate factors (TRFs) are defined as the quotient of each specific training medium performance characteristic to the equivalent characteristic of the

| CHARACTERISTICS / TRAINING MISSIONS | MANEUVERABILITY | | | SERVICE CEILING (100 FPM) | SPEED REGIME | | $\frac{1}{\text{GUST RESPONSE}}$ | MAX. RANGE AT SL | RATE OF CLIMB AT SL | | AVIONICS AND SYSTEMS SOPHISTICATION | POWER APPROACH CONTROL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | INSTANT. LOAD FACTOR | SUSTAINED LOAD FACTOR | ROLL ACCEL: BANK ANGLE IN 1ST SEC | | MAX. LEVEL FLIGHT SPEED | LANDING APPROACH SPEED | | | ENGINE OUT | ALL ENGINES | | |
| FAMILIARIZATION | 2.3 | 1.8 | 2.3 | 1.3 | 1.8 | 3.5 | 2.0 | 1.1 | 2.5 | 2.0 | 2.0 | 2.5 |
| BASIC INSTRUMENTS | 1.0 | 0.8 | 2.0 | 0.4 | 1.3 | 1.3 | 2.0 | 1.5 | 0.9 | 1.9 | 2.0 | 2.4 |
| RADIO (T.O. AND L) INSTRUMENTS | 0.9 | 0.1 | 1.4 | 0.3 | 0.3 | 3.6 | 2.5 | 2.3 | 3.4 | 1.9 | 3.8 | 3.8 |
| FORMATION | 2.6 | 2.4 | 3.0 | 4.0 | 1.6 | 1.0 | 2.6 | 1.8 | 0.1 | 2.9 | 0.4 | 1.5 |
| NIGHT FAMILIARIZATION | 1.0 | 1.0 | 1.5 | 0.6 | 0.4 | 3.4 | 1.4 | 2.0 | 2.4 | 2.0 | 2.3 | 2.6 |
| AIRWAYS NAVIGATION | 0.1 | 0.1 | 0.5 | 2.0 | 2.5 | 0.8 | 1.4 | 3.5 | 1.0 | 1.6 | 3.9 | 1.4 |
| OPERATIONAL (LOW LEVEL) NAVIGATION | 3.4 | 2.1 | 3.4 | 0.0 | 3.4 | 0.1 | 3.8 | 4.3 | 1.8 | 2.3 | 2.4 | 0.0 |
| AIR-TO-AIR GUNNERY | 4.4 | 4.3 | 4.0 | 2.6 | 3.5 | 0.0 | 2.9 | 2.1 | 0.3 | 3.1 | 3.9 | 0.0 |
| AIR COMBAT MANEUVERING | 4.9 | 4.9 | 4.5 | 4.1 | 4.1 | 0.0 | 2.0 | 3.4 | 0.8 | 4.6 | 2.4 | 0.0 |
| AIR-TO-GROUND WEAPONS | 4.6 | 3.4 | 4.4 | 1.5 | 3.3 | 0.0 | 3.3 | 2.5 | 0.6 | 3.5 | 3.9 | 0.0 |
| CARRIER QUALIFICATION | 2.4 | 1.0 | 3.9 | 0.3 | 0.0 | 5.0 | 3.6 | 3.4 | 4.6 | 2.8 | 2.8 | 5.0 |

RATE FROM ZERO TO FIVE IN WHOLE NUMBERS, WHERE 0 = TOTALLY UNIMPORTANT
5 = ABSOLUTELY ESSENTIAL

Figure 8 Mean Values of the Individual Scores (For Aircraft) baseline medium. The TRF, measures the influence of each medium characteristic on the time required to achieve a specific skill level. For most characteristics and training missions, this relationship is assumed to be linear as shown in Figure 9. The team of experts specify a maximum value (C) for each of the media characteristics. These maximums represent values of the characteristics above which there is no increase in training capability.

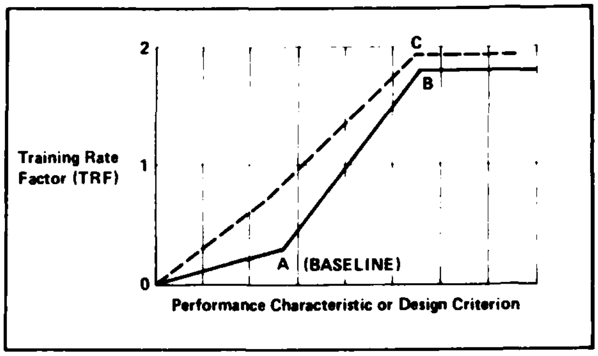


Figure 9 Relationship Between Training Rate Factor (TRF) and Training Medium Performance

The TRF versus performance characteristic relationship does assume a non-linear nature for certain characteristic/mission combinations which are approximated by a piecewise linear relationship also shown in Figure 9. The team of experts select break-point (A, B) on the piecewise curve and statistical analysis is applied to the selected values.

Except for transition hours, the entire calculation process for aircraft is shown pictorially in Figure 10. In this figure weighting factors obtained from Table I are multiplied by the ratio of TRFs from Table II to yield the values listed in Table III for each intersection of that matrix. These values are summed horizontally to obtain training effectiveness factors by mission for Aircraft-A as listed in Column (IV). Syllabus hours by mission for baseline Aircraft-B are listed adjacently in Column (V). The reciprocal values of Column(IV) are then multiplied by the baseline or existing syllabus hours for Aircraft-A which are listed in Column (VI). These syllabus hours by mission (Columns V and VI) are summed vertically over all missions to obtain the total training time for each aircraft. In block (VII), total training time for the baseline Aircraft-B is divided by the total training time for Aircraft-A, to compute the training effectiveness for Aircraft-A. This calculation process illustrated in Figure 10, corresponds to the constant rate portion of the generalized learning curve shown in Figure 7.

Hands-on media hours extrapolated from the existing syllabus using ASSEM as just described, are then compared with ISD hands-on syllabus hours by training mission as previously shown in Figure 6. If there is reasonable agreement ($\pm 5\%$) between syllabi, the ISD syllabus is used as input to the TMS submodel and the Resource Requirements Module of the TSCE Model. Otherwise, ASSEM and the ISD Submodel are iterated until agreement is reached.

<u>TMS Submodel</u>

The Training Management System (TMS) Submodel has been shown previously in Figure 3 as the final part of the Instructional System Module. As such, it is the focal point for integration of all

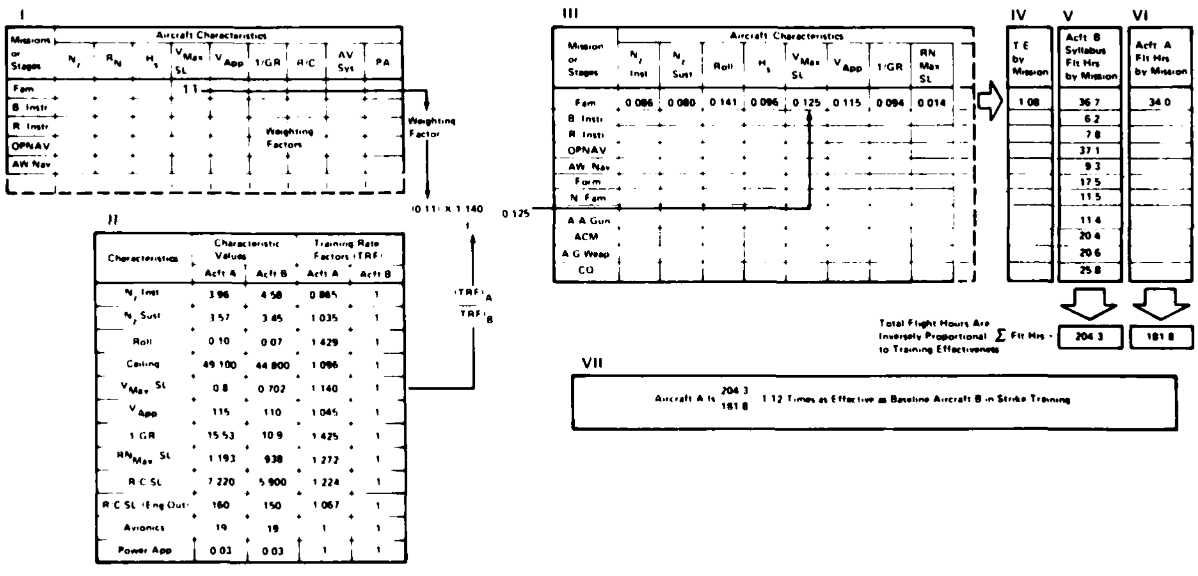


Figure 10 ASSEM Calculation (Example for Aircraft)

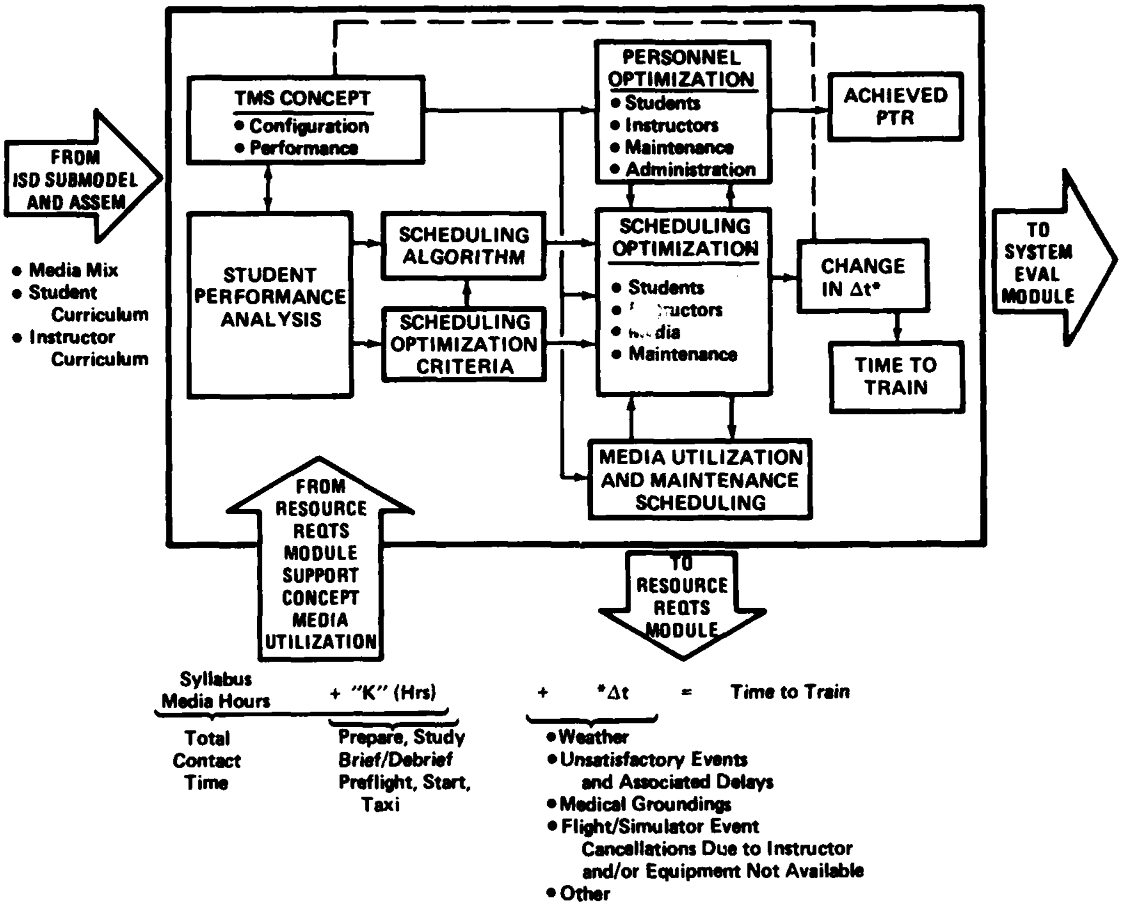


Figure 11 Training Management System (TMS) Submodel

scheduling and personnel requirements associated with the application of training system resources. Within the TSCE Model, it simulates the effect of the actual TMS on the training system. A simplified version of the TMS Submodel is shown in Figure 11. The core of this submodel is a scheduling algorithm which is used to define tradeoffs between the following system variables:

- Student attrition versus diagnostic and remediation time
- Instructor scheduling versus student scheduling
- Student scheduling by media versus media utilization
- Media utilization versus media maintenance scheduling

These trade studies provide the representative list of outputs shown below:

1. Student schedule and remediation plan by student performance profile.

2. Changes (if any) in student attrition policy.

3. Instructor scheduling by PTR, student performance profile, and training medium.

4. Schedule-optimized changes in personnel allocations by organization, base, function, and skill level.

5. Media utilization by student performance profile and remediation plan.

6. Maintenance scheduling by training medium for various utilization levels.

7. Detailed training and associated maintenance schedules by student performance profile.

8. Estimated student attrition by student performance profile and remdiation plan.

9. Change in t (refer to Figure 11) for various scheduling optimization criteria and support concepts.

10. Curriculum maintenance scheduling based on student response, media updates, fleet deficiences and changes in administrative procedures.

The ISD Submodel and ASSEM provide media mix, student curriculum, and instructor curriculum inputs to the TMS Submodel. Preliminary media utilization estimates and support concept characteristics are obtained from the Resource Requirements Module. The TMS Submodel provides achieved PTR and time-to-train data to the System Evaluation Module for use in training system efficiency calculations. Detailed training and maintenance schedules, changes in system personnel characteristics, and TMS characteristics are also routed back to the Resource Requirements Module for system life cycle cost calculations.

Resource Requirements Module

A simplified version of this module is shown in Figure 12. Logistic Support Analysis, maintenance schedules (from the TMS submodel), media R&M characteristics, initial maintenance and non-maintenance personnel allocations, and preliminary media quantities are required inputs to the simulation. The output from the simulation is a family of O&S trade data which relate media utilization and quantities, personnel allocations, spare parts, and GSE to O&S cost.

The acquisiton cost analysis starts with the preliminary definition of system acquisition alternatives based on state-of-the-art versus advanced technology segregation of training media and TMS components. Preliminary media quantities

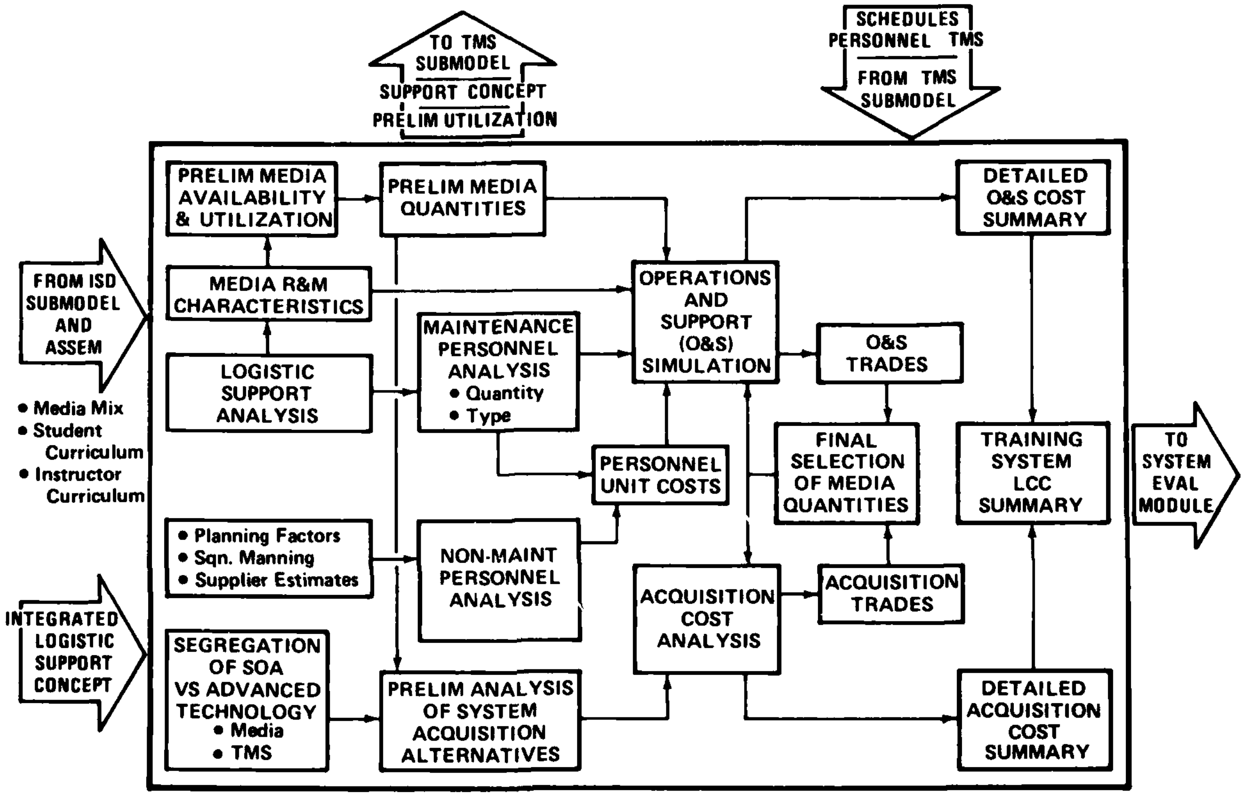


Figure 12 Resource Requirements Module

calculation of training media quantities, and calculation of life cycle costs all occur within the Resource Requirements Module. The ISD Submodel and ASSEM provide media mix, student curriculum and instructor curriculum inputs to the Module. The integrated logistic support concept to be evaluated, provides inputs for the Logistic Support Analysis which in turn, provides definition of media reliability and maintainability (R&M) characteristics, level of repair, initial estimates of maintenance personnel, general support equipment, training, spares/repair parts, and publications. Most of these items are routed as input data to an Operations and Support (O&S) Simulation. This event-oriented simulation tracks hands-on media (aircraft and simulators) through all daily events including operation, servicing, and maintenance which would normally occur in a training environment. Detailed training and and characteristics, supplier cost estimates and computerized historical regression submodels (such as DAPCA III, IALCCM, and MLCCM) are used to provide acquisition cost tradeoffs with quantities, risk, and schedule. Final selection of media quantities is based on O&S trades, acquisition trades, and optimized scheduling inputs from the TMS submodel. Feedback of revised media quantities to the O&S simulation and acquisition cost analysis allow final detailed O&S costs and acquisition costs to be calculated. These costs are summarized in life cycle cost format and become an input to the System Evaluation Module.

System Evaluation Module

This Module combines outputs from the Instructional System Module (effectiveness) and the Resource Requirements Module (cost) in a variety of evaluation formats which allow additional system alternatives to be defined, or a recommended system to be selected. The following criteria are used for system selection in the order shown below:

1. Training Effectiveness = Percent EOs completed to the conditions and standards specified.

$$E = \frac{(\text{EOs completed} = 1505)}{(\text{Total EOs} = 1530)} \times 100 = 98.4\%$$

2. Pilot Training Rate = Percent of PTR goal or requirement achieved with total EOs/student completed

$$\frac{(\text{Achieved PTR} = 520 \text{ Pilots/Yr.})}{(\text{PTR Goal or Requirement} = 570 \text{ Pilots/Yr.}))} \times 100 = 91.2\%$$

3. Training System Cost

- System LCC
- Average annual O&S cost per student for aircraft simulators, and academics

4. System Cost Effectiveness

- Aircraft O&S cost/Aircraft EO completed
- Simulator O&S Cost/Simulator EO completed
- Academic O&S Cost/Academic EO completed

5. Training System Efficiency

$$\text{Eff.} = \frac{\text{TLOs or EOs}}{\text{Time-to-Train}} \quad \text{and}$$

$$\text{Eff.} = \frac{\text{Achieved PTR}}{\text{Annual O\&S Cost}}$$

Each evaluation of a training system alternative provides values for all of the above selection criteria. These values, when compared with previous alternatives (baseline, existing system) may prompt the definition of additional system alternatives for evaluation which generate changes in any or all of the three basic modules (Input, Instructional System, Resource Requirement) of the TSCE Model as shown in Figure 2.

When training effectiveness, PTR, and training system efficiency have been maximized at the lowest possible system life cycle cost, a recommended system is selected and described as listed below:

- Printout of all TLOs/EOs
- Curriculum (Student, Instructor)
- Media Mix (Characteristics, Configurations)
- TMS Characteristics and Configuration (Hardware, Software, Communications)
- System Life Cycle Cost
- System Alternatives Evaluation Summary
- System Implementation Plan
- Preliminary Specifications for Training Media
- Integrated Logistics Support Plan

## CONCLUSIONS

This paper has described the Rockwell TSCE Model in its first generation of definition and application. It is both a complex and hybrid (manual and automated) process which represents a complex real world training system. Architecture of the Model is expected to evolve with continuing application and validation. Additional automation is planned for the future which will facilitate general purpose application of the Model to most training systems. Use of the TSCE Model expedites training system integration and provides a traceable rationale for system selection. Insertion of hands-on media design-oriented characteristics in the ISD Submodel has proven to be a useful innovation for linking the media design process to training objectives and hence to training effectiveness.

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# THE RELEVANCE OF COGNITIVE PSYCHOLOGY TO INSTRUCTIONAL TECHNOLOGY

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Instructional Psychology

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This paper discusses the recent shift in emphasis in psychology from behaviorism to cognitive psychology and the relevance of this development to the field of instructional technology. Several problem areas in the application of instructional psychology are discussed including, (a) the development of prescriptive handbooks/guidelines and (b) a preoccupation with hardware technology at the expense of instructional processes. Recent research is cited which suggests that the basis for many of the instructional designs incorporated in DoD and industry wide training systems may not be as firm as once thought. Adoption of some of the recent findings in cognitive psychology and a union of behaviorism and cognitive psychology are suggested as a partial solution of some of the above identified problem areas. Some of the advantages of adopting a decision oriented approach to the design of training systems are also discussed.

As a research psychologist for the Air Force, I am confronted regularly with the requirement to develop tools by translating what is known, particularly in the design of learning environments utilizing simulation, and delivering these tools in easy-to-use cook-book formats for use by the Air Force training community. Those of us who refer to ourselves as instructional technologist have often found this enterprise to be more difficult than anticipated. Before undertakings such as developing step-by-step procedures for the design of instructional environments can even have a glimmer of potential success, certain basic assumptions must be met. Among these assumptions are (a) instructional science is sufficiently developed to the extent that accurate predictions can be made relative to the instructional environment, and (b) what is known is sufficiently generalizable that it can be applied in diverse situations. What I hope to show in this paper is that instructional science has a long way to go before accurate predictions can be made relative to the specification of instructional environments and that many of the rules/principles of learning that have been the cornerstones of our thinking could be more aptly classified as exceptions rather than rules. As an alternative, I will discuss the potential advantages of adapting a student-centered cognitive perspective at the expense of our oftimes preoccupation with applying educational technology to an educational system that has not changed demonstrably since the days of Aristotle.

## Some Background

Perhaps a look at where the field of instructional technology emerged might shed some light on our current situation. During World War II, an active program of research and application in training involving programmed instruction and training devices offered some promise that the behaviorist learning principles of Guthrie and Skinner could be applied in military training. This promise intensified in the post-Sputnik era as psychologists were encouraged to apply technology and the systems approach to the improvement of training and education. A new generation of applied psychologists, were trained to apply modern technology to the design of learning environments. As a basic structure, the systems approach was lifted directly from weapons system development and became known as Instructional Systems Development (ISD) in the military. ISD worked quite well for such activities as analyzing system requirements and developing objectives and tests. However, when it came to the nuts and bolts activities of designing and developing instruction, instructional technologists found themselves in the position of pledging allegiance to theories in-vogue at the time, primarily those involving behaviorist principles of learning. My contention is that the field of instructional technology has not only adopted these principles but has cast them in concrete! For the past twenty years in military instructional technology we have been concerned with the application of modern technology to delivery systems for instruction with relatively little interest in the process of learning and instruction. As a result of this preoccupation with the technology delivery system and lack of emphasis on learning process many of us are beginning to agree with Liefer(1) that learning appears to be determined more by what is delivered rather than the delivery system. In spite of much evidence today, the military training community still places little formal recognition on the instructional features of training environments, particularly those involving training equipment. The primary consideration is still hardware, media, and the delivery system. Perhaps we should take a step back at this point to look at whether instructional science has matured sufficiently to permit "psychological engineering" of basic research into application.

## The Decline and Fall of Learning Theories

There is little doubt that Skinner's principles have been adopted in large measure in military instructional design (practice, reinforcement, knowledge of results, small steps). In this search for the philosopher's stone that will solve all problems, McKeachie has warned that "there is no magic way to transmute a stubborn, unmotivated individual into a learner" (McKeachie, (16). Not only have these simplified behaviorist formulations been adopted, they have also been given the status of eternal truths and are often proceduralized in handbooks. One recent development that argues against the advisability of such prescription and accompanying procedural guides, is the demise of many of the so-called laws of learning that were once thought to be immutable. McKeachie (1974) has documented the fall of Thornkike's laws of effect and exercise as well as Skinner's primary laws of practice, knowledge of results, immediate reinforcement, and gradualness. Recent research has indicated that (a) practice need not be overt, (b) knowledge of results does not have to be immediate, (c) reinforcement should be informative as well as immediate, and (d) learning does not have to take place in small steps to be effective. While recent findings have not destroyed some of the basic laws of learning, they have certainly been weakened and should only be applied based upon consideration of each unique situation.

Furthermore, much of the research on teaching methods has been very inconclusive. Duben and Taveggia (3) have concluded that there is no difference between instructional methods when final examinations are the criterion. Danseraue (4) has determined that there are no differences in instructional effectiveness when sequencing of instruction is varied. Aptitude-treatment interactions were also found to be insignificant in a review by Bracht(17). In general, much of the available research evidence indicates that there are, perhaps, more exceptions than there are rules in turn, arguing against the advisability of proceduralizing guides for the design of instruction by laymen. To use the analogy of building a bridge, the engineer must have stable rules and principles to apply, much as the instructional technologist must have stability before cookbooks for the design of instruction can be applied with confidence.

Prescribing the Learning Environment

The debate as to whether instructional science can be prescriptive in the scientific sense has been on-going for many years and has intensified lately. At issue is the distinction posed by Simon (5) between artificial and natural sciences. Is it possible to obtain scientific understanding of man-made institutions such as educational and training systems? Ebel (6) states taht education as opposed to learning is not a natural phenomenon, therefore, we do not need a scientific understanding of it; we need to make it work. A similar point is made by Hardie (7); he feels that we cannot explain and predict in education and training; we must do what is analagous to operations research (scientific preparation for decisions). Cronback (8) also favors the decision arrested approach for instructional science versus the conclusion oriented nature of natural science.

Glass (9) has asserted that too little is known to conceive of instructional science as a prescriptive, top-down science. His studies of average effect size in educational research have found only 1/3 of the variance accounted for in most research with little in the way of patterns emerging. With such variance and upredictability, how can policy be made by the scientist or engineer? Glass's conclusion was that there were too many unknown, immeasurable and uncontrollable factors to hope that a prescriptive science could emerge. The warning made by Judd (10) that "there is no such thing as pedagogical formulas - each new situation is unique," still appears to hold true today.

Based upon the above assessment, what hope is there for a science of instruction and a degree of structure for the instructional technologist? Both Cronbach and Glass have called for decision oriented research, what Glass (9) has referred to as general systems theory. In this approach, the amount of prediction possible in a system is assessed, and one learns to cope with the work around unpredictability.

Another issue is the nature of the subject matter that we work with. Prescription directions are written for the development of explicit behavioral objectives, for drill and practice, extensive feedback, etc. The demand has thus been to seek out subject matter that can be reduced to easily stated behavioral objectives that can be delivered via programmed instruction or computers. However, all knowledge that we may want to convey to a student is not explicit and may not fit into the programmed instruction format. Polyani (14) has distinguished between two forms of knowing: tacit and explicit; the tacit form being more of a subsidiary level of knowledge-that which cannot be made explicit. This distinction is similar to that discussed by Klein (15) between explicit tasks which can be proceduralized in the form of guidebooks and those tasks requiring recognitional capacity that cannot be proceduralized.

Technology, as it is currently applied, and procedural guides can be useful for learning environments involving learning concrete subject matter for which behavioral objectives can be specified; however, according to Broudy (2) "the more distinctively human aspect of experience - as distinguished from the robot aspect - seem to rely heavily on the tacit forms of knowing, and the latter will not take place automatically or predictably simply as the consequence of learning this or that set of facts or rules or acquiring this or that set of skills." The military instructional technologist, while not a cause of the situation, has gone along with the desires of the military training community to increase the explicit dimension of subject matter by removing all information sources that are not considered to be essential to explicit task performance. Thus, part of the trap we may find ourselves in involves the assumption that most subject matter can be delivered by the mechanical tutor approach developed by Skinner. While such an approach may be suitable for superficial, explicit drill and practice this form of learning, states Broudy (2), is "... necessary but not a sufficient condition for the more global, evaluative, and cognitive acts of the pupil, and indeed, it may be that without these larger schemata of values, goals, and commitments, the explicit learnings will be harder to achieve and render functional."

In the remainder of this paper, I will discuss how the adoption of a balanced cognitive perspective may aid the instructional psychologist in his search for what works.

Emergence of Cognitive Psychology

Many of the problems evident in the behaviorist philosophy of instructional design and specification can be traced to the conviction that the instructional materials and the instructor are responsible for learning, not the student. Thus, it is assumed, if every detail in the external learning environment is specified, the learning will take place. However, the cognitive perspective places much greater emphasis on the student and his internal mediation processes. As a result, each learning event is somewhat unique and cannot be prescribed in great detail. The instructional technologist must then focus his attention on the student, his motivation, his attention, his strategies for processing information; not on the instructional materials and delivery system alone. Once the instructional technologist realizes that it is not necessarily the materials or media that do the teaching, but instead the internal, cognitive mediation of the student, then the desire to reduce the instructional process to a series of procedural steps accompanied by infusions of more and more sophisticated media will be lessened. As stated by Cronbach (8), ". . . technology will be futile in education until a more basic understanding of the learning process is arrived at."

What, then, is to replace the structure that was provided with the "automatic" learning philosophy consisting of practice, immediate feedback, reinforcement, and overt action? The answer lies not in the replacement of many tried and true techniques, but more so in knowing when and where to apply such techniques, as cognitive elaboration, imagery, analogies, constructed meaning, and other techniques that aid students in discovering and creating reality-based learning, not automatic responding. According to Wittrock (11), the learner learns when he generates perceptions and meaning which is consistent with prior learning.

The cognitive approach places responsibility on the learner to generate his own meaning for instructional materials from his unique background, attitudes, experiences, etc. According to this view, cognitive structures must be formed to facilitate learning, and these structures can most readily be understood and remembered if they are associated with the idiosyncrasies of the learner.

## Future Research in Instructional Psychology

Faced with the lack of generality of many of the so-called laws of learning and the apparent failure of research in teaching methods, should the instructional technologist continue to develop procedural guides for the design of instruction and implement new technology for the presentation of instruction? If one adopts a cognitive perspective, then the conclusion of Berliner and Gage (13) that "the student codes, stores, and retrieves information in the same way, regardless of the medium in which the information is presented" is significant. This "equivalency" hypothesis casts doubt on the endless application of new media for the presentation of instruction that has been a favorite past-time of instructional technologists. Countless programs have been developed in the military for the presentation and management of instruction that change nothing but the medium of presentation. Additionally, many of the new technology media systems typically provide only one strategy for learning the instructional materials. Even when more than one strategy can be offered, the diversity of human information processing strategies tends to make such efforts extremely complicated and expensive.

The function of the instructional technologist of the future should be, as Berliner and Gage (13) have further suggested, "to arrange the conditions of the learner's external environment to support internal processes." New media and methods such as computer-based instruction, computer graphics, and media such as video disc, etc., have great potential in the instructional technologist" bag of tricks; however, they will continue to produce "no significant differences" if they are only used as replacements for other media. It is our task for the future to concentrate on what is going on inside the learner's head, as well as what kind of media is used to get the information in there. Obviously, we must continue our search to find solutions to immediate problems and apply what we know; however, we should remain cognizant of the pitfalls we encounter when we attempt to proceduralize data based on an inexact science and apply this inexactness to an enormously complex enterprise such as human learning.

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# INSTRUCTIONAL FACTORS IN MODERN TRAINER DEVELOPMENT

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## ABSTRACT

Trends in simulation training are reviewed, highlighting both the technological advances and the recurrent problem areas which have encouraged and plagued instructional system developers. These trends are expected to persist into the 80's. In general, the paper draws from the simulation literature of the late 1970's. It clarifies and diagnoses fundamental human factors issues in simulation training. Viewpoints of industry and military researchers are evaluated and integrated. Recommendations are based on existing data which support concrete problem-solving strategies. Research approaches are suggested for areas where knowledge gaps exist. The following topics are discussed: (1) Persisting issues in motion, fidelity, and user attitudes; (2) Interaction of training device instructional features, traditional instructor functions, and clarity of behavioral goals; (3) The psychosocial culture of simulator instructors; (4) Training effectiveness and transfer: The problem of evaluation; (5) Simulator sophistication and instructor workload.

## INTRODUCTION

A characteristic of man which sets him apart from the lower animals is his extensive use of tools to interact with his environment. Some of the first tools were weapons for defense. They were simple to understand and the users were easily trained. Through the ages, man has developed increasingly sophisticated tools which are progressively more difficult for trainees to comprehend. The instructor's job demands have increased in a direct relationship to the complexity of the machine. However, the ability of the trainee to comprehend and master the machine is inversely-related to the machine's complexity.

Seventy-five years ago, in the early years of aviation, pilots were trained on the job to operate their flying machines (many of which were not as complicated as today's automobiles). However, the advent of today's sophisticated airborne weapon systems, coupled with diminishing fuel supplies, have made the ground-based aircrew training device a necessity and a new set of educational and training parameters has surfaced. Modern flight simulators have introduced a new element into the pilot training program - a computer system capable of reproducing most of the dimensions of flight in a safe, adaptable, classroom setting.

The simulator set into motion an increase in technological creativity which rivaled the industrial revolution in terms of its impact on the techniques and direction of education and training. With the advent of modern trainers, another characteristic of man became evident: His idea that a more sophisticated machine would solve his problems. The approach to solving the pilot training problem has been focused primarily on developing more complex technology. A standard approach to pilot training with simulators has not been developed, and as Williges, Roscoe, and Williges note, the most common measure of training effectiveness, retention of skills, has been largely ignored in the evaluation of simulators (1).

The addition of a computer - assisted simulator can have profound implications for training beyond the obvious need to deal with complex hardware and software. The psychological impact on an instructor pilot, who had previously been in total control of a sophisticated airborne weapon system (a real-life, hands-on, natural classroom), but now is employing a sophisticated computerized weapon system trainer (WST) to impart skills to pilot trainees, is one such implication worth serious consideration.

The modern instructor has many responsibilities in addition to maintaining a positive relationship with his trainees. His efforts are directed at the orchestration of a sophisticated multidimensional learning system. Ideally, with the assistance of a computerized weapon system trainer, an instructor should be free to focus more time on the development of each individual student. Although many recent documents have assessed the mechanical technology available for improving aircrew training device fidelity, there seems to be a scarcity of research directed toward the instructor's needs. What are the human factors, the instructional factors, in modern trainer development?

Many of the problems we wish to discuss in simulation and educational technology go back a long way. For example, Edwin Link encountered skepticism and roadblocks in user acceptance with his first instrument flight trainer, the "Blue Box". This device, intended for general aviation usage, was largely ignored by that

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community and found its early acceptance instead in the entertainment field. Whether aviation's rejection of Link's trainer was based upon its low cost or its humble origins in the piano and organ business, remains unknown.

By 1931 Link had become a wiser marketer, and was able to triple his delivery price to $1,500. He also taught an aviation-naive Naval officer to fly by instruments in the Blue Box, and Navy acceptance was quick to follow (2). The Blue Box was not a flight simulator *per se* but a cockpit procedures trainer with no serious claim to realistic aircraft feel. However, it did have motion and was a trend-setter in that respect. Fifty years later we remain uncertain about the need for realistic motion in flight simulation. Modern visual systems coupled with certain characteristics of human psychophysiology make it possible for simulator students to behave as though they are moving without actually moving.

This paper is an outgrowth of a routine literature search through documents dealing with instructor/operator console input systems. It became apparent to the authors that certain fundamental problems in training technology remain unsolved or, at best, glossed over. This condition exists despite (perhaps even because of) great advances in training device sophistication. For example, simulator builders and buyers place great emphasis on realism and physical fidelity; yet as Fink and Shriver point out, the factual basis for this approach (and its implications for transfer of training) is unclear (3). On the same point, Adams reminds us that a simulator is a teaching machine, not an earthbound aircraft (4). The problem of simulator fidelity and motion is discussed below, as is the related issue of instructor/student attitudes toward simulation. This general domain encompasses situations where training device sophistication and mandated instructional features may have outrun the supporting empirical data.

A different disjunction between supporting data and instructional technology is apparent when one examines the training and responsibilities of instructors. This problem represents a case in which a problem area is glossed over or perhaps is concealed in a smokescreen of device sophistication. The reader is likely aware that the training of instructors for their role is largely unstandardized, and perhaps even haphazard in some settings. We will discuss five issues in training technology, highlighting current practices, and the likely myths related to each issue. The issues are (a) Motion, Fidelity, and User Attitudes; (b) Interaction of Training Device Instructional Features, Instructor Functions, and Clarity of Behavioral Goals; (c) The Psychosocial Culture of Instructor/Operators; (d) Training Effectiveness, Transfer and Evaluation; and (e) Simulator Sophistication and Instructor Workload. Although our approach draws mainly from the documents of other researchers in the instructional technology field, we hope that our psychological/educational emphasis will stimulate new directions in thinking about these old problems.

## PERSISTING ISSUES IN SIMULATOR MOTION, FIDELITY, AND USER ATTITUDES

That motion systems contribute substantially to flight simulator costs is well known. But as Caro has argued, we can with confidence neither eliminate motion from simulation nor insist upon its inclusion in the interests of simulation training effectiveness and efficiency (5). Caro cites the study of Jacobs and Roscoe in which beginning flight trainees failed to show a transfer advantage from washout motion compared with no-motion control subjects (6). Citing five other studies on the comparative benefits of simulation motion, Caro suggests that motion may improve the efficiency of training if not the effectiveness, and that a dynamic flight simulator may give the trainee a slight edge in control strategies arising from inflight emergency maneuvers. [An analogy suggests itself: Investing in simulator motion systems may be like buying and saving new-issue postage stamps. At worst, the investor retains a useful commodity (though subject to inflation shrinkage) but enjoys no capital gain. In the best case, some stamps may return a large future dividend, provided the bearer is at the right place at the favorable moment.]

Once a decision in favor of motion is reached, the question of required degree of motion realism (aircraft "feel" and handling qualities) comes to the fore. The Link was an effective trainer whose motions were but crude caricatures of real airplane responses. Simulator "feel" is an area where, from design to eventual evaluation, pilot opinions are the dominating criteria. Yet, as Caro points out, training effectiveness seems not to follow from motion realism in any orderly manner (5). Adams criticizes this dependence on pilot ratings for evaluating flight simulators along broader lines than motion considerations *per se* (4). Adams questions whether high physical fidelity inevitably leads to high positive transfer. He notes that the transfer/similarity relationship can be decoupled, in that mockups have produced as much positive transfer as high fidelity simulators, and that transfer has been recorded in situations manipulated to actually reduce physical fidelity (4). A similar argument, advanced by Fink and Shriver, was that simplified training devices are adequate for bringing military maintenance trainees to the apprentice level. High skills development can be left to the on-job environment (3).

An excellent brief summary of literature bearing on the fidelity/transfer relationship was prepared by R. L. Miller, who also derived several models of the general relationship between simulator cost, effectiveness, and degree of physical fidelity (the original model coincidentally, was prepared by R. B. Miller, also at Wright Patterson AFB, in 1954) (2).

We turn now to the role of user attitudes (or acceptance) on training device effectiveness. Hopkins has said that

> Almost any kind of simulator can be used effectively in a well-designed training program with specially-trained instructors and highly motivated instructors and students (7).

This optimistic statement implies that we could get by with less in the way of motion systems and physical fidelity and still train effectively if we had well-trained and enthusiastic instructors and highly-motivated students with good imaginations. The problems in instructor preparation will be discussed later, and we will confine our remarks here to user motivation (in the present context, we assume that "motivation" and "morale" mean similar things, and that the word "attitude" is a close relative of the others.)

Anyone who has slogged through the shifting sands of motivation research would likely agree that unless the human performer is internally motivated, external incentives are not going to sustain task commitment for very long. The trainee must want to be trained and to perform the task subsequently. The motivational demands on the instructor are equally significant. We shall later address the motive/attitude complex of instructors and will only point out here another "axiom": Students readily pick up the attitudes of their instructors about simulator fidelity, usefulness, and general worth. In short, the acceptability of a training device appears to be in part a function of students' attitudes about that device, and students' attitudes are in turn partly (if not wholly) a function of their instructors' attitudes about the device.

We generally believe that pilot acceptance of simulators increases with degree and fidelity of simulation, and that reduced fidelity is likely to engender negative student pilot attitudes. Hopkins charges that this belief is "...largely a myth that has been fostered and perpetuated by those interested in development of more complex and more costly simulators. There is no evidence to suggest that pilot acceptance of simulators is a significant problem" (8). Hopkins then makes one of the more novel (and concrete) suggestions for assuring pilot acceptance to be found in the training literature:

> For the beginning student pilot, acceptance of considerably less than *perfect fidelity in the simulator* should be possible if flight in the aircraft is made contingent upon achievement of specified levels of performance in the simulator (p. 538).

The psychologist recognizes this strategy as the "Premack Principle," which involves using a highly preferred behavior to reward prior performance of a less-preferred behavior (9).

Would it be irresponsible to hypothesize that strong positive student and instructor attitudes (and high task-oriented motivation on the parts of both) would not only compensate for lowered physical fidelity, but perhaps even reduce simulator motion system requirements? Such a hypothesis may have some appeal from a cost viewpoint, but Alsobrook's data suggests the hypothesis is in trouble (10). Alsobrook surveyed air force pilots and navigators as well as top-level managers from six major air force commands. Strong hints of negative attitudes toward simulation in lieu of flying hours were manifested by both aircrews and commanders. However, attitudes did tend to become more positive as training devices increased in instructional adequacy, and in fidelity. The negative attitudes were pertinent to *simulator quality*, obsolescence, and to the difficulties of simulating the flying characteristics of fighter aircraft (with instructor skill and dedication receiving generally good marks). Taken together, Alsobrook's data imply that we fall short in the area of cultivating strong positive attitudes toward simulation.

## INTERACTION OF TRAINING DEVICE INSTRUCTIONAL FEATURES, INSTRUCTOR FUNCTIONS, AND CLARITY OF BEHAVIORAL GOALS

> Even now, there is substantial applied research evidence that much of the training conducted in expensive simulators could be accomplished in less-expensive devices _if_ the training programs used with them were properly designed and conducted... a realistic simulator is a poor substitute for competent training (11).

Although it is currently fashionable to attack the school of psychology known as behaviorism for its disinterest in (or denial of) mental processes and physiological factors in learning and motivation, in fairness to Skinner and others we must recognize behaviorism's enduring contributions. These include revolutionary psychiatric treatment models, strategies for managing training with the retarded, the delinquent, and the culturally deprived, techniques for modifying nonproductive behaviors of industrial workers, and programmed instruction.

The breadth and subtlety of behaviorism's influence is evident in our unquestioning acceptance of the value of positive feedback/reinforcement in training management, and in our strong emphasis on establishing clear behavioral goals in instructional system development. The latter is perhaps behaviorism's most useful legacy for skills training settings: Know exactly what behaviors your trainees must acquire; decide exactly the level of performance you will accept; and pretest your trainees to determine the magnitude of the training task. A bumper sticker for instructors might read "Where are we now? Where are we going? How will we know when we get there?"

The importance of having concrete behavioral goals is fairly obvious when we consider teaching young people to fly modern aircraft. Instructors will also benefit from having clear behavioral goals. This is true both in terms of their own training as instructors, and in terms of their teaching relationship with their students (What do I do? How exactly do I do it? When do I do it?) The literature suggests, however, that in training instructors we do our poorest job of providing behavioral guidelines. Instructor training is nonstandard at best, and extensive practice in operating the training device to fully exploit its features is acquired on-the-job (maybe)!

On the full exploitation of simulator instructional features, Blaiwes, Puig, and Regan have called attention to the occasional communication gap between the simulator developer/builder and the system user (12). This gap, which develops shortly after delivery and installation, serves to keep the user ignorant of some of the device's instructional features, thereby blocking full exploitation of training capability. Caro refers to this state of affairs as one where the simulator is "dropped over the fence at night" (13). The implication is that after delivering the training device, the manufacturer fails to provide adequate follow-on support.

The literature also reflects a growing interest in syllabus preparation where simulator instructional features are emphasized, in contrast to earlier approaches in which the syllabus was more closely bound to a real aircraft. Related steps in specifying instructor behaviors are exemplified by Charles' functional analysis and breakdown of IP duties (14); and by Montemerlo's discussion of current simulator instructional features (15).

Although Montemerlo's list of instructional features points in the direction of concrete instructor responses, his purpose was to explore instructional features which could be automated, thus freeing the instructor for a more managerial role. This suggestion is in line with the notion of many in the (military) training community that instructors should be eliminated altogether (thus eliminating the thorny problems of instructor/operator station design and instructor/operator jurisdictional disputes). However, we see totally automated training as still over the horizon in aviation. Certainly the beneficial effects of automating certain aspects of simulation training seem self-evident, particularly in the area of student performance analysis. Consider a simulator with the capability to diagnose subtle student errors, or recognize maneuvers needing remedial practice, all without specific input from the instructor. This "smart grader" or teaching assistant would then automatically switch into a part-task trainer mode, repeating problem segments, reassessing student response providing slow-motion and playback as required, and perhaps presenting a visual or synthetic vocal text in support of its tutoring. The human instructor can do all this, but there is no assurance that it is done uniformly well. The instructor could use this new freedom to observe and assess the larger picture of the student's response to the general learning environment (i.e., he can make value judgments).

Perhaps the push for maximum fidelity in flight simulation has dominated current research thought to the point where the features which can best be utilized through computerized simulation training have been overlooked. What technology exists now to aid the instructor in evaluation and analysis of trainee performance? How are instructor pilots trained to utilize these unique simulator capabilities? It may well be that instead of being scornful of the synthetic flight trainer's lack of fidelity and "feel" we should consider its full feature potential and the unique training capabilities it offers the instructor.

The challenge is to achieve an appropriate menu of training device features to support instructors in their teaching functions so that students can attain the training goals set for them. At present, we seem technically better at specifying training goals and instructor activities than we are at isolating the optimal array of device features.

This latter issue received emphasis in a paper by Cream, Eggemeier, and Klein, whose criticality-frequency-difficulty (C-F-D) analysis assists the training device user-builder design team to determine mandatory instructional features and exclude less-cost-effective features (16). A summary of the C-F-D decision model cannot do it justice here, but in essence the model says, "If a feature is not critical in meeting training goals, if the feature represents a situation rarely encountered in the real environment, and if the feature is technically difficult to achieve, possibly irrelevant, and certainly costly, then exclude it."

The key to applying the C-F-D analysis is the clear specification of training goals in student behavior terms. On this latter point, Williges, Roscoe, and Williges have asked a provocative question bearing on the matter of behavioral goals: What is ideal pilot behavior and what is the standard for recognizing correct performance (1)? Do the appropriate concrete behaviors involve staying in tolerance, performing within the norms, or the judgments of experts? Expressing training goals in concrete behavioral terms may be more easily said than done.

## TRAINING EFFECTIVENESS, TRANSFER, AND EVALUATION

Perhaps the thorniest problem of all is the evaluation problem: It impacts the student, the instructor, and the device itself. We have subscribed to the positive transfer of training model, that behaviors learned in one setting will carry over to a different setting to the extent that stimulus and response elements in the two settings are similar. In general, that model has served us well. It is the basis for the quest for psycho/physical fidelity and, as the rationale for realism in military training, was given good marks by World War II GIs for its preparation for combat. As Adams has reminded us, positive transfer is what we're about, and positive transfer tends to grow out of fidelity (the key concept being similarity) (4).

After reminding us of the paucity of solid data on positive transfer in aviation training, Adams points out that the actual level of transfer obtained has been of the order of 10-25%, and he offers sharp criticism of the transfer paradigm as applied to aviation training. His most provocative point is that the outcome of the test for positive transfer is (must be) a foregone conclusion, in that

> The subjects of an experimental group must fly the aircraft well on the first flight after simulation training. If not, they would not be allowed to fly, and so there would be no measures and no experiment (p. 713).

Adams offers instead an alternative rating plan which emphasizes (1) whether the prototype simulator meets the provisions of the handful of fundamental and reliable laws of learning psychology, and (2) whether the device is sufficiently like other similar devices which we believe to be effective trainers. It is easy to share Adams' discouragement with the training transfer paradigm when one considers comments such as Valverde's that the contradictory results which characterize the training transfer studies might be traced to confounding or unassessed variables in the criterion measures, the student group assignment procedures, the instructor, and the instructional sequence (17).

Adams takes critical aim at another practice common in training device evaluation, the reliance on pilots' ratings in judging the degree to which the simulator accurately models the (aircraft) system (4). He grants the ability of pilots to assess a flight simulator for its physical fidelity, but questions whether pilots are trained to detect crucial and subtle elements of psychological fidelity. He reviews data showing that simulator ratings change as both pilots and simulator students gain experience; and he discusses data that challenge the assumed relationship between fidelity and student performance. Finally, Adams attacks the premise implicit in the current rating method that a flight simulator is a ground-based aircraft, reminding us instead that a flight simulator is a teaching machine and that it should be rated as such. Clearly, this paper is important reading.

## THE PSYCHOSOCIAL CULTURE OF INSTRUCTORS

It is clear that teachers will retain their crucial role in instructional systems in the foreseeable future. It is also clear that instructor recruitment, preparation, attitudes, work schedules, and reward systems are currently subject to great variance. These aspects illustrate what we mean by the term "psychosocial culture"; and, although there is little hard evidence that social and psychological aspects of instructors either enhance or degrade training effectiveness, common sense tells us that there are good and poor instructors, good and poor training programs, and many intermediates on both counts.

Caro, Shelnutt, and Spears discuss the characteristics of more effective and less effective training units and provide extensive observations on the qualities and behaviors of instructor personnel associated with both (13). From their observations emerges the following profile of instructors in effective units: The instructor was an above-average aircrew member who sought the training assignment to diversify his career; he is a mature and stable person whose final selection was made by his eventual instructor peers; and his rapport with both students and peers was good. His instructional duties were given top priority in the training unit, and he enjoyed flexibility in scheduling his secondary duties so that conflict among his assignments was minimal.

As an instructor-in-training, this new member of an effective training unit first trained as a student, getting the full course in both the aircrew training device and subject aircraft. Then he observed the full training of two students under direction of a senior instructor who was also his tutor on device capability and operation. Next, the instructor trainee gave segments of training to two senior instructors playing the student role (performance reviews and critiques were part of this phase of instructor training). Finally, the instructor trainee conducted supervised training with two "real" students, an activity analagous to "practice teaching."

If we are to support the crucial role played by the instructor in simulation settings, our near-term strategy ought to be to take steps to enhance the instructor "culture." Those steps should include standardizing and formalizing the recruitment of instructor personnel along lines described by Caro et al, structuring and formalizing the training of instructors (again, see Caro et al), assuring that the training assignment has the highest priority among the officer's other duties, and generating a proper and uniform reward structure both during the instructional tour of duty and in the subsequent assignment of instructors (13). By no means should we tolerate situations where instructors and training managers voice clearly negative attitudes about the worth of training devices in general, or where a conscientious instructor actually loses ground in the personnel rating arena relative to his non-instructing peers.

Along those same lines, we need to assure that proficiency ratings of instructors, already an elite group, are not depressed by adherence to a forced-choice rating system not designed for upper-level groups. Caro is explicit on the role played by instructors and other supportive elements in instructional systems (11):

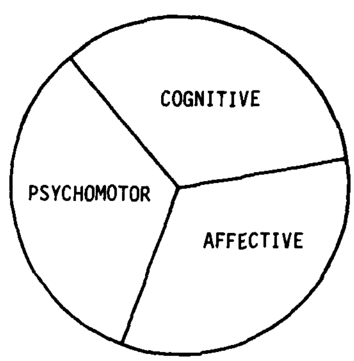
> It is becoming evident...that the training vehicles-the simulators principally, but also the training aircraft-are less important in many respects than are the instructors and the organization and content of the training programs (p. 504).

### SIMULATOR SOPHISTICATION AND INSTRUCTOR WORKLOAD

The aircrew training device instructor's workload includes the following: Preparation of student data, syllabus development, operation of instructor console, evaluation, brief and debrief, training of other instructor pilots, data management, and noninstructional duties. This listing does not contain all the workload responsibilities of an instructor but it helps to illustrate that he must wear three hats simultaneously: Pilot, educator, and computer operator. Most reports on simulation training concentrate on the instructor's role as a pilot and computer operator. The instructor workload section of this report will focus on the instructor's role as educator.

Many engineers, pilots, and design personnel tend to view the training simulator as a ground-based aircraft rather than a teaching machine. This attitude focuses attention on how to develop greater physical fidelity, and the standardization of the computer input devices at the instructor/operator station to provide better simulator control. Perhaps some insights into the educational aspects of training would help in designing simulation technology which would enhance the instructor's role as educator as well as pilot and computer operator.

The instructor's educational workload has many facets, including course content, course presentation, trainee performance analysis, and maintenance of a constructive relationship with his trainees. An instructor's conception of a trainee has an effect on this relationship. Figure 1, Trainee Cognate Areas, illustrate aspects of a trainee with which an instructor must interact.




Psychomotor

- Eye-hand coordination
- Control inputs
- Movement sequence
- Emergency response
- Control "feel"
- Reflexes

Cognitive

- Decision making
- Prediction
- Memory
- Judgment
- Evaluation

Affective

- Attitudes
- Morale
- Self-Image

FIGURE 1: TRAINEE COGNATE AREAS

This diagram illustrates some of the human elements which have an effect on learning quality, quantity, and rate. Educationally, the instructor's workload involves interaction with all three of the cognate areas: psychomotor, cognitive, and affective. The training which an instructor receives to prepare him for interaction with these three trainee areas is not adequate in most programs, especially in the affective area. Charles reviewed simulation training operations and concluded that instructor consoles are not designed for training implementation and that the instructor pilot is trained in neither simulator utilization nor in how to instruct (14). For example, Caro *et al* indicate that instructor training covers a broad continuum ranging from brief "checkout" on the aircrew training device instructor console, to a comprehensive and systematic training program (13). Thus, the preparation provided to simulation instructors is inconsistent at best, and recognition of the need for a standardized training approach is one of the first steps toward defining the training program for instructors.

The workload of competent instructors involves a repertoire of behaviors much broader and more intricate than the simulator syllabus guidelines would indicate. Just as the professional flyer has a much greater understanding of flight than could be gained from reading through a flight procedures manual, the professional instructor has more understanding and control of instructional methods, media, and systems than a course syllabus would supply.

Many opinions presently exist on the issue of who should instruct and what the workload should include. Perhaps the answer to the following question would help in solving the issue: Is the instructor a dedicated pilot assigned to a tour of teaching in a ground-based aircraft or is the instructor a dedicated educator at the controls of a sophisticated air training device?

It appears that instructor workloads have increased along with achievements in simulator sophistication, to the point that instructors run the risk of being unable to function as teachers because of the demands of console operation. Moreover, some weapons system trainers (WST) require several instructors working in concert. Bolwerk describes the actions of an S-3A instructor crew (device 2F-92) and uses the phrase "...Mack Sennett comedy..." to describe their antics (18). He also recounts a case where two stand-alone devices were integrated into a WST which, it was thought, would reduce the number of instructors. Contrary to expectation, the WST required the full complement of instructor personnel from both stand-alone devices.

Reliability problems also became more frequent with increasing sophistication, and reliability problems produce down-time which, in turn, produces scheduling difficulties (7). As scheduling difficulties arise, there can develop a temptation to move toward a square-filling utilization approach to training. For example, if a syllabus calls for X number of fault insertions, and run time has been foreshortened by simulator down-time, the result can be a rapid-fire program of fault insertion with student management of those faults preordained to be inadequate: Batching leads to botching, so to speak; and student attitudes about simulation training can suffer as a result. Sometimes high sophistication leads to information overload on the part of the instructor. Information overload can result from building more sophistication into the device than is actually needed. Cream et al describe one simulator designed to provide hard copy of student performance parameters, updated 15 times a second (16). The resulting mound of printout paper was neither anticipated nor desired by the user.

A common proposal these days is to automate many of the manual tasks of the instructor, particularly in reference to console operation. The goal is to free the instructor to make value judgments about student progress, much as an automatic pilot frees an aircraft commander from routine tasks. Automation would make the instructor the manager of training rather than the operator of the simulator. This is a noble goal, and most would agree that we ought to try to achieve it. At the same time, we need to anticipate a likely tradeoff here. It is possible that console function automation, in reducing the motor/manual workload of instructors, might simply be traded for a greatly increased cognitive workload where the instructor now has to scan more displays, integrate more information, and make more decisions, though his hands rest on the console work surface. In that sense, the job of instructor might take on some of the stressful and undesirable aspects of the job of an air traffic controller in a dense traffic environment.

Even in the best case, where instructor workload is pared to a minimum by an intelligent automated computer, there are risks. Not only do we widen the instructor-student interpersonal distance, but moreover, the instructor is left standing in the shadow of the computer. These possibilities call for some thoughtful and careful research in instructor task analysis and function allocation.

An opposite sort of outcome of console automation is that automated training devices might give the instructor too little to do. Our guess is that this unlikely circumstance would stimulate instructors to become creative and devise some effective off-line instructional follow-on strategies which, according to Bolwerk, continue to elude the training community (18).

A technique which holds promise for both alleviating instructor workload and as a basis for an instructional follow-on strategy is that of peer training as described by Caro (11):

> Trainees themselves are used to assist fellow trainees in many simulator training activities. This technique has been found particularly useful with respect to cognitive problem-solving activities such as those which occur during navigation problems. Simulators are particularly well-suited for peer instruction because the instructor can be removed from the cockpit area without creating flight safety problems with relatively unskilled trainees (p. 506).

The issue is not whether we shall find simulator training acceptable, because our only alternative is to maximize the present state of the art. The resistance we are seeing is reminiscent of the reactions of the old horse cavalrymen to the advent of mechanized fighting vehicles, and to the broader resistance of the military establishment to airpower in the early days. Our current confusions about the role of the eventual user in simulator design, about the essential instructional features to be included, about developing simulator-based syllabi, about the number and pacing of fault insertions, about the roles of instructor and technician, about optimum usage of the device, and about student, instructor, and device evaluation will all pass in due time.

## CONCLUSIONS AND RECOMMENDATIONS

In this last section we make a series of suggestions that seem to follow from the literature. Some of the suggestions involve the less-timid pursuit of trends and practices which are psychologically sound but only tentatively endorsed in the training community. Other suggestions imply research directions; and still others might be interpreted as criticisms of directions followed in the past.

### On Instructors

Instructors should be recruited primarily (and hopefully) from the ranks of volunteers. They should be demonstrably good at their aircrew jobs and be likeable people. Their final selection should be recommended by the pool of instructors whose units they shall join. Their attitudes about simulation should be honestly positive, but not unrealistic. Instructors should be trained systematically and rigorously, covering everything from full device utilization to student counseling. Their instructional duties should have top priority, with secondary duties which "come with the territory" never allowed to conflict with the training mission. Clearly, there are serious manpower implications here, both in terms of Tables of Organization and the current military manpower state of affairs (i.e., difficulties in retaining senior aircrewman and skilled technicians).

The same person should serve as instructor in the aircraft and in the simulator for a given student. This reduces nonuniformity when it comes to evaluating student progress and increases training standardization (at least for his students).

By no means should instructional tours of duty be allowed to penalize instructors in terms of their falling behind on their career tracks because of such factors as loss of flying hours. Moreover, special care needs to be exercised in rating flight instructors by means of instruments weighted, as they often are, to a standard of mediocrity. Never should the old saying, "those who can't do, teach" be permitted to become true in the training enterprise.

### On Simulators

Training device design teams should include senior instructors from the user population as well as training psychologists. Designers have access to a tool similar to the Criticality-Frequency-Difficulty analysis to help them aim for the simplest possible training device needed to do the job. Simulators should be evaluated primarily for their teaching qualities and only secondarily for their "handling" qualities. It is common knowledge that one shortcoming of simulators is in reference to their lack of ultimate realism. Instead of berating the simulator for its benign, safe, and relatively artificial quality, we should turn the logic around and accept simulator "gentleness" as the defining positive characteristic, thereby exploiting the unique qualities of the simulator as teaching machine.

We might even relax our adherence to the training transfer model which, if Adams is right, we psychologists might have oversold (especially the "identical elements" part). Instead, or in addition, we ought to grade our devices for their ability to provide reinforcement, stimulus response learning, perceptual learning, and cognitive learning.

Apparently too many simulators are "dropped over the fence at night," used mainly as procedures trainers, produce too much hard-copy, break down too often, and have built-in features of which too many users are kept ignorant. Here, builders ought to assign knowledgeable field representatives who visit simulator sites regularly to assure full and correct exploitation of the simulator's features and to gather intelligence for the next version of the device.

We should proceed with thoughtful efforts to automate certain aspects of simulator operation, particularly in the area of student performance analysis. It ought to be possible for a student to visit the simulator on his own time, insert his cassette (or performance token earlier produced by that simulator), and have the device tailor a remedial lesson to that individual based upon the data he inputs.

On the continuing issue of flight simulator motion, perhaps we should elect a training mode (undergraduate, transition, or continuation) and isolate a few training units where long-term experiments on the contributions of motion might be undertaken, with no-motion assigned to alternate students or classes. An optional experimental design, borrowed from medicine, is a sort of rolling-block design, where motion is inserted at progressively later stages in the training of subsequent groups of students. Similar experiments could be done in the fidelity and visual systems areas, with the aim of determining the minimum effective level of fidelity for adequate training. Our design philosophy ought to emphasize efficiency and simplicity, not to mention reliability.

### On Instructional Systems Development

A simulator is a teaching machine, and a strong positive aspect of teaching machines and programmed instruction is that students can proceed at their own paces. Here, the plea is for flexibility in syllabus design and presentation to enable a student to slow down where needed, accelerate where appropriate, and skip unnecessary steps. This flexibility should also extend into the area of simulator utilization schedules where down-time is compensated for not by jamming the rate of fault insertions, but by solutions generated by a thoughtful training management team. Too often simulator utilization schedules take on the characteristics of a five-day tour of Europe.

Finally, we should encourage opportunities for peer training as well as self-training as augmenters of regularly-scheduled sessions. Along these lines there is a strong need for creative work in the area of off-line post-simulator training exercises. Lately, we have been thinking about something resembling the athletic practice of team viewing and critique of game films.

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# CLOSED-LOOP TRAINING SYSTEMS THROUGH THE APPLICATION OF INSTRUCTIONAL FEATURES

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## ABSTRACT

Training effectiveness requires that the training "devices" be closed-loop systems with properly applied and integrated instructional features. This paper presents a generic approach to the application of instructional features based on the perspective gained through two diverse development efforts. The paper emphasizes the systematic application of the techniques such as cues, prompts, feedback and measurement to enable an objective and appropriately controlled training environment. It presents for comparison the results of two separate efforts to develop programmed instruction and automated performance measurement features on a) the 14A2 ASW Tactical Team Trainer and b) the ASN-118 Navigation Computer System (NCS) Maintenance Procedure Simulator (MPS). A comparative analysis describes the difference in an instructional features approach as governed by the training situations that are supported.

## INTRODUCTION

Rapidly increasing costs of training devices, as resources become more limited, have resulted in a need for demonstrated training effectiveness to ensure that the devices meet intended training support requirements. Training effectiveness requires that training devices be closed-loop systems with properly integrated instructional features. It is the use of these features that ensures the principles of learning are applied to the training process. This has not always been the case. It was noted by Polman et. al. (1979) that "advanced control and display technology has been exploited seemingly to cover all contingencies rather than to permit conduct of necessary instruction activities in an efficient manner." Isley and Miller (1976) indicated that in many modern simulators, incorporated instructional features were not even being used.

The military's needs for training systems are extremely diverse in nature, including aircraft simulators, portable weapon systems, radar and ECM operator/team trainers, sonar and ASW team trainers, etc. In the past few years, training technology has been expanded to include maintenance trainers for numerous avionics, weapons systems, and other systems. In many of these systems, attempts have been made to apply the technology of instruction with varying degrees of success. The complexity of applications precludes a comprehensive discussion of these approaches within the scope of this paper. However, the point is that an increasing awareness has grown for the need to advance the development of guidelines and a more advanced understanding of the applications of learning principles and instructional techniques to the many diverse training devices.

Instructional features (automated or instructor activated problem control capabilities) will be more appropriately integrated into a device to the extent that they are viewed as part of a closed-loop system. The term "closed-loop" in the context of this paper refers to the generation of sufficient data to identify on-going training problems and the use of this data in appropriately controlling the training environment. Therefore, emphasis is placed on the application of cues, prompts, performance measurement and feedback. The 14A2 Team Trainer and MPS maintenance trainer development efforts provide excellent examples of fundamental differences in training situations that are encountered in the use of trainers. Some lessons have been learned from these efforts. Based on the perspective gained from these two efforts, criteria and rationale for the application of cues, prompts, feedback and performance measurement instructional features are described that are necessary to ensure training effectiveness through closed-loop training systems.

## BACKGROUND

### The 14A2 Device Development Effort

The 14A2 ASW Team Trainer supports training of USN and USCG personnel in the fundamental procedures and advanced ASW team operations. The 14A2 trainer complex, shown in Figure 1, provides training for the sonar, underwater fire control, Combat Information Center, and bridge subteams. Although both basic operator and team training is supported, the performance measurement system development focused on team training. Team training emphasizes team coordination, and assumes knowledge of basic operator procedures. (This does not imply assumed proficiency). During training exercises, the performance of individuals and subteams has been evaluated by use of subjective checklists. Primary emphasis in evaluation has been on overall team performance. Quantitative performance measures such as "number of targets submarines hit" reflect this approach. While such generalized performance measures may be important, they do not ensure training effectiveness. When the target is not hit, general team measures insufficiently define specific team weaknesses and strengths. Reliance on subjective evaluation of key or critical actions or events does little to ameliorate this situation.

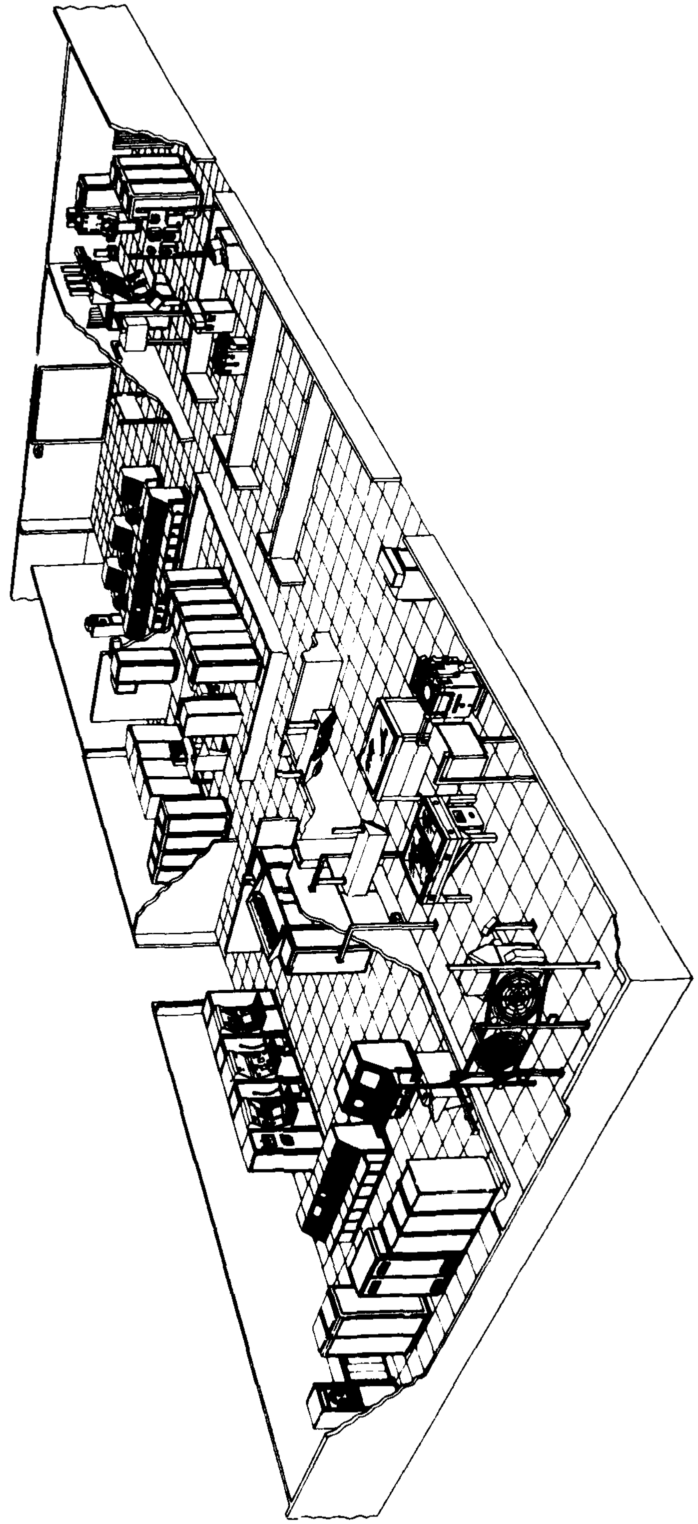

Figure 1. 14A2 ASW Tactical Team Trainer

The need for advancements in team performance measurement systems has long been recognized (Hall and Rizzo, 1975). A closely related problem is that of defining how team training differs from individual training and the resultant differences in performance measurement. In a study conducted by the Navy Training Analysis and Evaluation Group (TAEG) it was concluded:

> "There is much research to suggest that individual proficiency is the key to effective team performance and that coordination required within a team naturally emerges as a result of higher levels of individual proficiency."

In an approach to establishing quantitative and objective performance measures for the 14A2 trainer, Honeywell developed a performance measurement paradigm which was basically in agreement with the TAEG group conclusions. The paradigm referred to is the "Three Dimensional Matrix" performance measurement model (Yeager and Bell, 1977) illustrated in Figure 2. The three dimensions of the model are:

1. Subteams
2. Exercise phase
3. Performance measurement categories

Individual performance measures can be used to provide feedback and knowledge of results to individual team members. Scores can be summed by subteam, exercise phase or measurement category. Composite scores, as shown in Figure 3, are helpful in diagnosing specific strengths or weaknesses by subteam, exercise phase, or measurement category.

The Three Dimensional Matrix model provided the basis for two related studies conducted for the Naval Personnel Research and Development Center (NPRDC), to define a set of quantitative ASW performance measures. In these studies a set of 48 candidate performance measures were evaluated based on data collected from six ASW teams trained on four exercises each. Identical category exercises were selected for each team. The results of these studies indicate that approximately 28 of the candidate measures proved to be meaningful and to have face validity. A comprehensive discussion of the individual performance measures and their application is provided in the resultant NPRDC report (Bell, 1979). Individual examples of measures will be described in the following sections related to a discussion of more generic applications.

## The MPS Development Effort

The purpose of the MPS is to supplement classroom training of E-3A aircraft flightline organizational level maintenance activity for the ASN-118 NCS. The MPS, shown in Figure 4, houses both the student station and instructor station in a single integral console. The student station provides a) a replication of the E-3A Navigators Panel, b) a representation of the E-3A flight deck, c) a trainee panel to simulate maintenance actions, and d) a projector system to provide student cues and error feedback. The MPS enables the student to conduct part task and complete maintenance procedure lesson units, controlled and monitored with step-by-step programmed instruction. The instructor may select 1 of 100 distinct simulated malfunctions in the NCS as lesson units in the MPS. The trainee conducts checkout, trouble analysis, component isolation and replacement, and post-replacement checkout procedures, in order to complete a complex lesson unit. Extensive use of cues and feedback messages guides the student through the lesson.

## A Basis for Comparison of ASW Team and Maintenance Training

In order to provide a common basis for comparison of ASW team and maintenance training, it is suggested that the Three Dimensional Matrix performance measurement model used in ASW team training can be applied to maintenance training. In maintenance training, the model would be a simplified two-dimensional model; categories of measurement, and phases. Obviously, the subteams dimension does not apply. The training phases for maintenance are checkout, trouble analysis, component isolation, and replacement and post-replacement checkouts in that the student sequences through these procedures in order. The application of instructional features will be related to categories of performance measurement, and the training situation as the student progresses through phases of the training exercise.

# APPLICATION OF INSTRUCTIONAL FEATURES

## A Comparison of the Training Situation

The first step in developing a systematic approach to the application of instructional features is to define the primary characteristics of the training situation being supported by the trainer. Individual training features can then be selected on the basis of such criteria as 1) compatibility with the training situation, 2) practicality, 3) relevancy to the type of learning being addressed, and 4) ability to integrate features within the situation. A summary comparison of the instructional situations for ASW team training and E-3A NCS maintenance training is presented in Table 1. The differences in the instructional situations are stated in terms of types of learning tasks and emphasis in training philosophy.

It is considered beyond the scope of this paper to describe each difference in instructional features in detail. However, three salient aspects of these differences should be noted:

1. Emphasis with respect to the type of learning.
2. Emphasis with respect to categories of performance (i.e., performance measurement).
3. The role of key events in the training situation governing the application of a given category of measures.

Emphasis in training situation differences and key events provided the basis for resultant differences in the approach to instructional features in the 14A2 ASW Team Trainer and the MPS maintenance trainer as described in the following section.

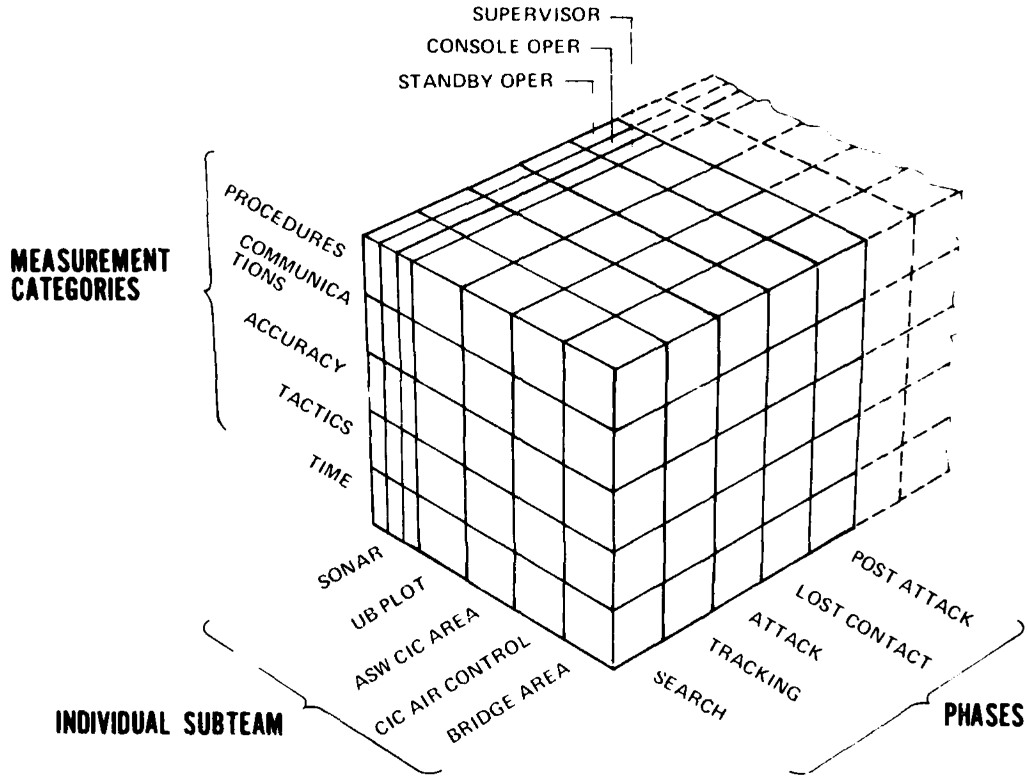


Figure 2. Three Dimensional Matrix Model

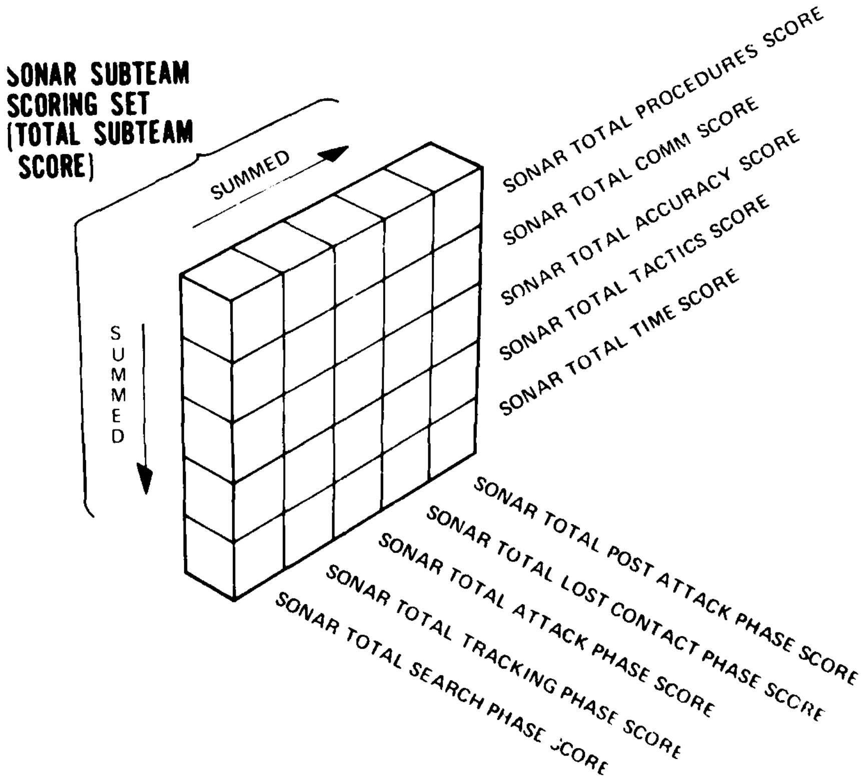


Figure 3. Sonar Subteam Composite Score

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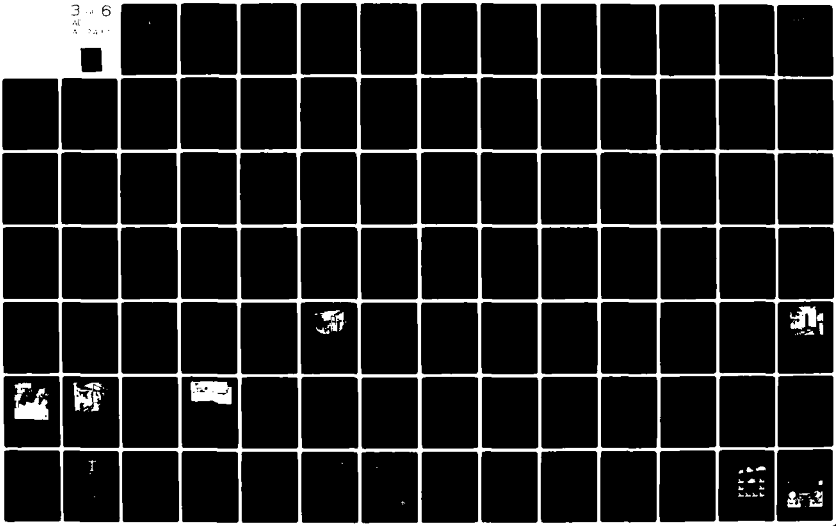

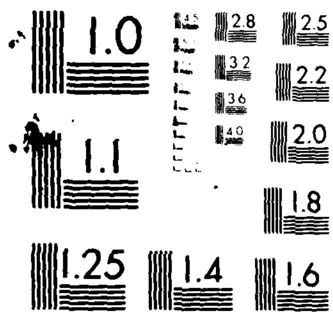


MICROCOPY RESOLUTION TEST CHART
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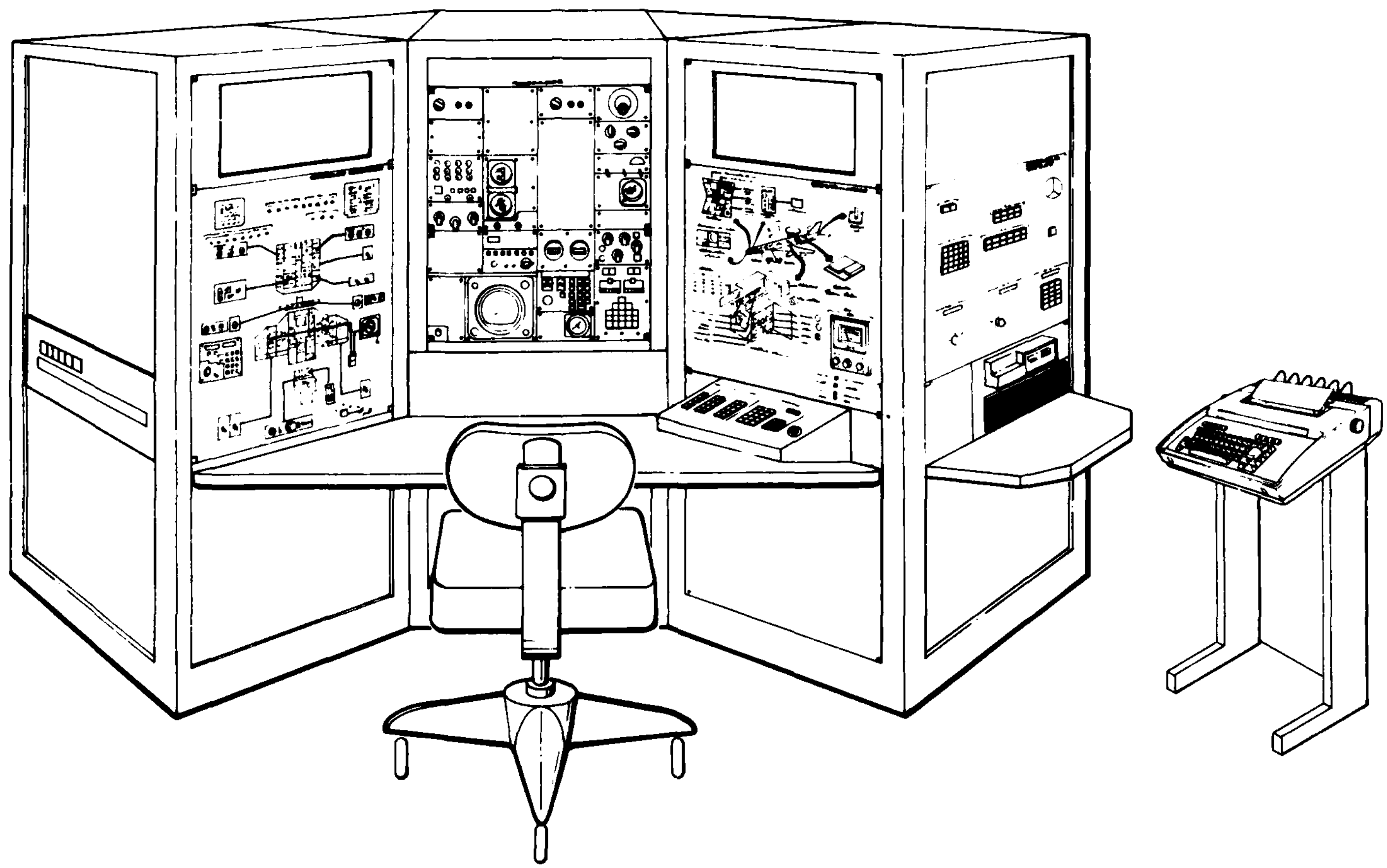

Figure 4. NCS Maintenance Procedure Simulation (MPS)

## The Application of Cues, Prompts and Feedback

The application of cues, prompts and feedback is primarily influenced by the type of learning experience being supported. When fixed behavioral (procedure following) sequences are being trained the intent of instruction is to control and shape behavior. Shaping behavior through the application of cues, prompts and feedback in accordance with learning principles is well understood, and readily applied. The maintenance training situation supported by MPS is well suited to the use of these features, and makes extensive use of cues and feedback. Appropriate use of formal and thematic prompts guide behavior to ensure that only correct produres are followed. When incorrect actions are taken, immediate or delayed feedback correct the behavior and reorient the student to the proper stimulus discrimination i.e., interpretation of displays. Cues and feedback can be provided virtually at every step taken by the student as an instructional frame or unit.

The instructor may select an "aiding level" that determines the level of cues and feedback to match the experience level of the student. At the "beginners" aiding level, a student error results in an immediate alert signal and feedback to the student; as well as subsequent directions. The "intermediate" aiding level delays feedback and affords the student the chance to correct the error (or repeat the task) without extrinsic error feedback. This enables student behavior to be shaped increasingly toward reliance on intrinsic feedback system status indicators, through a form of diminished intensity cueing and feedback. Finally, the "test" mode provides no cues or feedback, and only monitors and records errors.

Several factors should be noted about the application of cues, prompts and feedback. First, it is assumed that the training situation enables self-paced instruction. Time must only reflect proficiency of learning and should not be a critical aspect of the environment to which the trainee must adapt. Second, prompting must not detract from on-going, continous task performance. Finally, cues and feedback must not interfere with the interactive process. Taken in this context, cue and prompts do not appear to be compatible with the ASW team training situations.

Emphasis on tactical decision making in a dynamically evolving scenario provides a radically different learning experience than that in maintenance training. The trainee must learn to act in a real-time environment. Further, learning the tactical consequences of a bad decision, and how to recover may be as important a learning experience as how to make the initial correct decisions. Second, the trainee must focus on developing motor skills in coordination with continuous visual feedback from complex displays, while communicating with other team members. Finally, even in those cases where prompting may benefit one team member, it may disrupt the interactive process, degrading the training situation for other team members. Therefore, the ASW team exercise must be experienced in its entirety in order that individuals learn to deal with evolving situations in real-time. Individual prompting in general is a disruptive application of instructional features. Feedback should be provided at the completion of the unit, (i.e., in post-exercise evaluation). This will be discussed in the following section in terms of performance measurement.

It is still desirable to avoid "negative learning" which allows students to practice incorrect behaviors. Therefore, lack of guidance, through prompting, should be compensated for by real-time performance measurement and instructor monitoring capabilities. Further, the instructor should be provided a manual "freeze" capability to temporarily halt the exercise when performance becomes degraded to the point of being questionable. Continous monitoring by instructors always carries with it the potential for reduced objectivity and standardization. Therefore, proper application of real-time performance measurement and problem control of critical parameters to avoid the negative learning situation are essential to assist the instructor.

## The Application of Performance Measures

The application of performance measures is governed by the training situation emphasis in categories of performance and key events in the training lesson/exercise scenario. Table 1 clearly shows a dichotomy in the ASW team training and maintenance training emphases with respect to categories of performance. In maintenance training, the emphasis is on procedure following. ASW team training places primary emphasis on communications, tactics, and accuracy in that order. Performance with respect to time is important in both situations, however, the application of time measures is dependent on key events. The performance measures establisned for each system reflect the training situation differences.

The MPS provides a post-exercise student performance printout. An example of this printout is shown in Figure 5. This printout lists each error committed and the amount of time into the lesson at which it occurred. The step number within the maintenance Technical Order (T.O.) procedure, criticality, and repeated steps are all noted along with the total exercise time. The printouts are designed to allow the instructor to review each procedural error, referencing it to the maintenance T.O. and to bring to the students attention specific information, steps, etc., i.e., discriminative stimuli, to which the student must attend. Time is strictly an overall measure of proficiency.

The development of the ASW automated performance measurement approach addressed several categories of pertormance measurement. Table 2 provides a few examples of the many performance measures determined to be valid and meaningful in evaluating performance. In the ASW team training situation, the least emphasized category of measurement is (operational) procedures, the direct inverse of the maintenance situation.

In addition to the emphasis placed on categories of performance measures, the impact of key events on the application of performance measures is significant. A comparison of time measures provides an excellent example of this aspect of evaluation. In maintenance training the key events are efficient transition to each phase of the procedure. In general, time is not a critical factor in performing any given step. That is, the system state changes only with each student

TABLE 1

COMPARISON OF INSTRUCTIONAL SITUATIONS

| ASW TEAM TRAINING | ORGANIZATIONAL MAINTENANCE |
|---|---|
| 1. Dynamically evolving scenario, wherein the sequence of events is a function of on-going tactical decision making. Emphasis on learning to control the situation as it progresses through the exercise phases. | 1. Relatively fixed sequence of events. Emphasis is on learning to adhere to defined procedures as the student systematically progresses through the phases of a maintenance lesson unit. |
| 2. Emphasis is on verbal communications. Accuracy of data, as well as timeliness of decisions relative to key events is measured. | 2. Verbal communication is non-existent or de-emphasized in performing tasks (except for instructor assistance). |
| 3. Man-machine interface involves motor-skills coordination with interpretation of displays (tracking, cursor alignment, plotting, etc.). | 3. Man-machine emphasis is communication of equipment status via equipment response and the sequence of interaction. Physical tasks are perfunctory and often simulated as in the MPS. |
| 4. Emphasis is on accuracy of interpreting properties of complex display patterns (intensity, movement, consistency, shape, etc.). | 4. Individual displays are more simplex (indicators, volt meters, etc.) but more numerous. The complexity is in interpreting the interrelationship of many indicators and the relationship to maintenance actions. |
| 5. Time is a critical factor with respect to the decision making process and coordination. It may or may not measure proficiency depending on key events. | 5. Accuracy in procedure following is the critical factor. Time is only a measure of proficiency. |
| 6. Post-exercise evaluation by the instructor focuses on a) tactical decision making, b) accuracy of motor skills tasks to enable accuracy in decision making, and c) communications coordination. | 6. Post-exercise evaluation focuses trainee on ability to follow procedures and proficiency in completing tasks. |

Trainee: ____________________

Date: ____________________

| | |
|---|---|
| Exercise No. | 149 |
| Aiding Level | 1 |
| Feedback Mode | 2 |
| Time Allotted | 45 Minutes |
| Time Delays | Truncated |

| T.O. Step | Error Type | Time |
|---|---|---|
| 1b | Critical Error | 1:15 |
| 1b | Repeat Task | 1:31 |
| 17d | Error | 11:10 |
| 17d | Repeat Exercise | 12:24 |
| 14c | Error | 5:27 |
| 24f | Error | 17:24 |
| 37 | Repeat Task | 24:19 |
| 51 | ON FLY FAULT ACTIVATED | 39:12 |
| 51 | Run Time | 40:47 |

Figure 5. MPS Student Performance Printout

TABLE 2

EXAMPLE ASW TEAM TRAINING PERFORMANCE MEASURES

Communications (all subteams)

Number of Omitted Data Items
Number of Late Data Items

Accuracy

Sonar Range and Bearing Error (Mean, Standard Deviation, RMS)
Doppler Error (Mean, Standard Deviation, RMS)

Time

Time to resolve multiple echoes (contacts)
Time to activate torpedo alert

Procedures (all subteams)

Number of (control positioning errors)

action, and is not evolving independently. Therefore, time is consistently a measure of one aspect of performance;proficiency. The total lesson time is an overall measure of proficiency. In MPS training, the time taken to correct any given error is a measure of the students ability to recognize and recover from the error, and therefore, a measure of proficiency.

The ASW team training problem presents a more varied application of time measures than maintenance. In some cases, the amount of time is critical. For example; the time taken to respond to the detection of a hostile weapon fired at ownship and alert the ASW team is such a measure. In other cases, the amount of time is a poor measure. The time from hostile submarine detection to attack is a measure often proposed, but a poor indicator of performance. In one case the time taken may reflect proficiency in coordinating an attack. In an other case, the team may be ready for an attack, and holding, while the ship maneuvers for a better tactical position. Finally, time measures can reflect coordination rather than proficiency. It is how close an action occurs to a key event rather than how long an action takes. In an ASW scenario, the tactical situation is constantly evolving, partly independent on any student actions. An example of a time measure of coordination is the time of an ordered maneuver by the ASW officer based on relative ownship, assist ship, and target position and motion (key positions). The actual amount of time taken to complete the task is fairly standard. Coordination is the key to maintaining control, and the learning experience.

One final point should be made about the impact of the training situation on performance measures. It was noted earlier that each step in maintenance training could be viewed as a distinct instructional frame or unit, whereas ASW team training was a continously evolving situation that should not be disrupted. As a result, the MPS measurements are frequency (number of occurrences) measures and time measures. The ASW performance measurements deal with time intervals, of performance, rather than discrete points. Therefore, summary statistical measures (means, standard deviations) are appropriate and often essential for evaluation of performance in a single exercise.

## CONCLUSIONS

The comparison of ASW team training and maintenance training deal with only two extreme situations. A variety of training situations remain to be examined in order to identify all of the considerations in the applications of instructional features. However, the comparison suggests some generic guidelines in a systematic approach to the application of instructional features. These guidelines are:

1. Define the categories of performance in the training situations. These categories will reflect the classification of performance measure.

2. Identify the components of the training situation. Attention should be given to:

   a. Dynamic versus static aspects of the environment.

   b. Complexity of behaviors and man-machine interface.

   c. Complexity and nature of displays.

   d. Training phases and key events.

3. Identify the categories of performance that are emphasized and the priority of these categories.

4. Identify discrete actions versus behavioral sequences or intervals that must be measured and evaluated.

5. Define critical points of man-machine or team member information flow and the conditions under which instructional control features can be integrated.

Experience with the 14A2 team trainer and MPS substantiates the need for adherence to these guidelines. This approach to the systematic application of instructional features will play a significant part in ensuring effective closed-loop training systems through cues, prompts, feedback and performance measurements.

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# INSTRUCTIONAL DESIGN FOR AIRCREW JUDGMENT TRAINING

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## ABSTRACT

Aircrew training design has made significant progress during recent years. However, significant gaps exist both in design methodology and existing programs with respect to systematic training of higher level cognitive skills. Training in decision-making and judgment is currently haphazard at best. After a brief review of recent literature, the paper presents a conceptual model of judgment performance. The theoretical model is an extrapolation from Jensen (1977) and unites the variables of cognitive complexity, time availability, uncertainty, and stress in one coherent model. The model is used to examine current aircrew training and to develop new training strategies for improving judgment performance.

## INTRODUCTION

The secret to being a good pilot is good judgment. Very few people familiar with the art of flying airplanes would disagree with that statement. However, the art of teaching judgment to a pilot is a secret. Very few people who deal in the magic arts of training design would quarrel with that statement.

Judgment is a part of the "RIGHT STUFF" of Thomas Wolfe's newest novel. A good student is supposed to come with a good foundation stock of that right stuff. During training, he might increase it slightly by mere association with his instructors who have plenty of it, of course. But the rest of it, the delta which will make him full member of that exclusive elite of good pilots--that delta he will acquire by experience, by hours and hours of flying, by countless exposures to situations which require that rare quality of good judgment.

The correct teacher, then, of judgment, is experience for us ISD people who are so adept in teaching facts, concepts, rules, and even such high level skills as problem-solving, grudgingly leave the field to Master Experience when it comes to instilling that most desirable of all skills, the skill of making good and reliable judgments. That this is not a desirable state of affairs, and that the guild of instructional designers in cooperation with the learned colleagues from the field of psychology should do something about it, goes without saying.

This paper presents a conceptual framework for thinking about the problem of judgment and a discussion of the applications of this conceptual framework to training design and research. This may sound like an ambitious endeavor, but if it provokes nothing but your passionate criticism, the cause of finding the instructional treatment for judgment may be advanced.

The most recent effort in the area of judgment training is a project sponsored by the Federal Aviation Administration (FAA). Phase I of this project resulted in a report by Jensen and Benel (1977) from the Aviation Research Laboratory at the University of Illinois. Their report was based on a literature review which, to quote the authors, "led to many studies related to pilot judgment in a peripheral way, but only to one which was directly related" (Thorpe, Martin, Edwards and Eddowes , 1976). The Jensen and Benel report is essentially the first broad-based attempt to answer the three questions: "What is judgment?", "Can judgment be trained?", and finally, "Can judgment be evaluated?".

The first question is answered with a definition which consisted of two components:

1) A cognitive component which deals with establishment of alternative actions and the selection among them, and
2) An affective component or motivation which effects such selections among the alternatives.

In a later paper, Jensen expanded this definition to include a continuum from perceptual judgments to cognitive judgments (Figure 1).

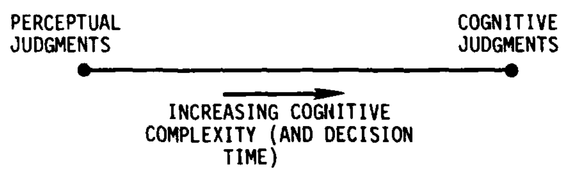


Figure 1. Judgment Continuum Based on Cognitive Complexity and Decision Time (Jensen, 1978)

According to Jensen, primarily perceptual judgment is associated with low cognitive complexity and little time available for decision making. At the other end of the continuum one finds more analytical forms of judgment, called cognitive judgment, characterized by high cognitive complexity and plenty of available decision-making time.

The question, "Can judgment be trained?" was answered positively. Judgment is trainable if

Instructional Systems Design (ISD) methods are used for training design. The instructional designer, however, finds little operational advice which would enable him to "do his thing" in the area of judgment, except the recommendation to use situational training techniques.

The question dealing with the evaluation of judgment was also answered positively. Judgment performance can be evaluated if such an evaluation is based on criteria established by behavioral objectives and if the training situation is carefully structured. Again, however, Jensen and Benel offer no practical method for structuring the training situation.

Neither the recommendations for training, nor the recommendations for evaluation follow from the definition. The definition itself clearly is comprehensive enough to encompass all that might be called judgment, but it is not sufficiently precise to allow the logical deduction of training or evaluation methods.

In addition to the Jensen study, there is a fairly extensive body of literature which deals with aircrew decision making in a probabilistic environment. A good example of this literature is a study sponsored by the Naval Training Equipment Center analyzing requirements and prescribing a methodology for decision training in operational systems (Saleh, Leal, Lucaccini, Gardiner, Hopf-Weichel, 1978). Decision making, however, is only one, although the most complex one, of the cognitive activities to which the pilot must apply judgment. The recommendations from this body of literature, therefore, may not be applicable over the entire spectrum of the judgment phenomenon.

The training designer, if he is not to leave the field of judgment training to Master Experience, needs a definition of judgment which is both broad enough and precise enough. It must be broad enough to include the entire judgment spectrum and it must be precise enough to permit the deduction of design principles for training. In the following, an attempt is made at a redefinition of the concept of judgment and the major variables which influence judgment.

## JUDGMENT MODEL

### Definition

Fundamental to the understanding of the notion of judgment is the idea of uncertainty in the sense of lack of information. Judgment must be exercised when less-than-perfect information is available, i.e., under conditions of uncertainty. To express this in more colloquial terms: judgment is making more or less educated guesses if one does not know everything one should know in a given situation, i.e., when less-than-perfect information is available. For example, the pilot who cannot determine how far the wheels of his airplane are off the ground during the final phases of his landing approach, must exercise judgment in establishing the correct landing attitude. The same is true for a pilot in an air-combat situation, when faced with an opponent whose personal capabilities he does not know, whose weapons he cannot identify, and who flies an obviously modified aircraft of an otherwise familiar type. This pilot, too, is operating under conditions of uncertainty, i.e., under conditions of a relative lack of information, and must exercise judgment when he goes through the complicated decision-making process of determining his next maneuver, i.e., in deciding and planning how to best wipe his opponent out of the skies.

These two examples, which range from simple to complex cognitive tasks, illustrate another important point. This point is, that judgment is not a type of intellectual skill as identified, for example, in Gagné's hierarchy of intellectual skills or in Markle's, Bloom's or Merrill's taxonomies of objectives. Rather, judgment is exercised, and must be exercised, when performing any cognitive task, regardless of its taxonomic classification, when less-than-perfect information is available, i.e., whenever a cognitive task of any type must be performed under conditions of uncertainty.

Under conditions of zero uncertainty, with all necessary information available, the mode of cognitive operation in any cognitive task is not judgment, but a different mode of operation which one might simply call <u>determination</u>, since the outcome is essentially <u>deterministic</u> as with the solution of a mathematical problem. On the other hand, under very high or extremely high uncertainty conditions, the mode of operation might more appropriately be called <u>intuition</u>, a mode which might no longer be <u>classified as</u> a rational/cognitive mode of operation, as it borders on irrational phenomena such as the famous "sixth sense" or ESP.

The concept judgment, therefore, can be defined with three relevant attributes:

- It is a mode of cognitive operation which is delimited by strictly deterministic modes on the one side, and by intuition on the other, where the borderline between judgment and intuition is less sharp than that between the deterministic mode of operation and judgment.
- It occurs under conditions of uncertainty.
- It is applicable to any type of cognitive task, regardless of its taxonomic classification.

If this definition clarifies the concept of judgment, it does little to explain directly why different people faced with the same situation will operate with different degrees of success under conditions of uncertainty, i.e., will demonstrate anything from bad to good judgment. Given the relative paucity of the literature on the topic of judgment, it appears safe to postulate that the ability of a person to exercise judgment depends primarily on four factors or variables:

1. <u>The difficulty of the judgment task</u>, where the concept judgment task is defined as any cognitive task which must be performed under uncertainty conditions;
2. The <u>available repertoire of relevant cognitive strategies</u>, where cognitive strategies are defined in the sense of Gagné and Briggs (1974) as capabilities allowing a person "to <u>manage</u> the

processes of attending, learning, remembering, and thinking."

3. The level of stress at the moment of tasking and the amount of stress generated by the task;
4. The available repertoire of affective coping mechanisms for dealing with stress.

This appears to be quite a plausible set of factors which can be subdivided into two subsets, the first dealing with cognitive factors and the second dealing with affective factors. Face validity of this set can easily be demonstrated with air combat. Whether or not a given pilot will demonstrate good judgment in an air combat situation, would certainly depend on his mental and emotional makeup and the objective, and/or perceived danger and difficulty of the situation in which he finds himself. Physical stress and the physical condition of the pilot certainly influence judgment performance also. They are excluded here because the intent is to shed some light on the cognitive and affective aspects of judgment training only. Besides that, the physical conditioning part of pilot training really does not present any problems.

In the following now, the factor difficulty of the judgment task is defined with more precision and its relationship with stress is investigated.

Difficulty of the Judgment Task

One of the variables which determines the difficulty of a judgment task is obviously the degree of uncertainty. The higher the degree of uncertainty, i.e., the less information is available in a given situation, the more difficult it will be to exercise judgment. Uncertainty and information are understood here in the sense of Shannon's Information Theory which defines information as a measure for the reduction of uncertainty resulting from the reception of a message, and which establishes the bit as a measure of information. The uncertainty variable can thus be quantified in bits and the uncertainty of a situation is given by the amount of information in bits that is necessary for reducing uncertainty to zero. In a binary situation, for example, the toss of a coin, the information "heads" has the value one bit and reduces uncertainty over the outcome of the coin toss to zero.

A second variable which determines the difficulty of the judgment task was identified by Jensen as Cognitive Complexity. One possible quantification of this variable is the number of discriminators and operators in an algorithm which describes the cognitive task. For example, the task of identifying a concept with three relevant attributes, can be described with an algorithm containing three discriminators and three operators. Saleh et al. (1978) have described several emergency decision tasks in algorithmic fashion, using decision trees.

The third variable is quite obviously the Time Constraint, i.e., the time available to perform the task. A task of a given complexity and uncertainty obviously becomes more difficult the less time is available to perform it.

For the sake of conceptual convenience, more than for reasons of theoretical necessity, these three variables can be arranged as the three axes of a spatial, orthogonal system of coordinates, or as three orthogonal vectors originating from the same point. Difficulty of the judgment task is then simply defined as the resultant vector.

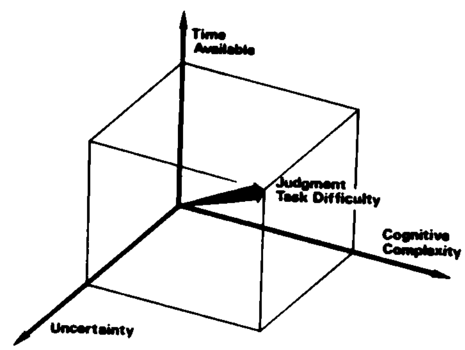


Figure 2. UCT Model: Judgment Task Difficulty as a Function of Uncertainty, Cognitive Complexity, and Time Constraint.

For the sake of rhetorical convenience, the three-axis model might be called the UCT model, the acronym being derived from the first letters of the three variables.

Stress

Before the application of the UCT model to training is discussed, the relationship of judgment task difficulty to stress or to affective variables must be analyzed. In order to characterize this relationship, an important distinction, the distinction between the flight problem and the background problem, must be made. Jensen and Benel make essentially the same distinction when they speak of rational and irrational pilot judgment. This distinction can best be demonstrated by an example comparing two flights. The purpose of Flight No. 1 is a cross-country ride for a private pilot license. One hundred miles before his destination, the pilot receives a weather report which tells him of an unanticipated deterioration of the weather between his present position and his destination, with his destination itself still under VFR conditions. The pilot now has to exercise judgment in deciding whether to continue to his destination, to his preselected alternate, or to some other airport, and whether to fly through the weather, around the weather, or above the weather. In Flight No. 2, exactly the same situation exists. One hundred miles before his destination, the pilot receives the very same weather report. He flies the same aircraft, etc. However, the purpose of this flight is not a cross-country check ride, but an important business meeting, or a reunion with a lover, or a medical emergency.

In Flight No. 1, the pilot is faced with solving a pure flight problem. He will exercise his best judgment, given the facts and uncertainties of the flight situation alone. In Flight No. 2, the same flight problem exists, but in addition to that, a second problem which can be called the background problem, is to be solved. The background problem and the flight problem obviously interact with each other. It can be hypothesized that if this interaction between these two problems produces conflict and/or cognitive dissonance (as defined by Festinger), a component of stress is introduced into the situation which can be considered additive to the stress already existing at the time the problem emerged.

Stress, however, arises not only from conflict created by the interaction between the flight and the background problem, but also from the flight problem itself. The difficulty of the judgment task in the pure flight problem may also give rise to stress. The relationships between stress and task difficulty have been extensively investigated in human factors research, and by and large allow the conclusion that performance will initially rise with increasing stress up to a certain point, where it rapidly drops off to near zero level. Among flight instructors in military flight training, this phenomenon is well known as the so-called "IQ Dump". There are probably very few pilots, especially in military aviation, who have not at one time or another experienced this phenomenon themselves, either in training or during operational flying. By the way, military aviation is emphasized here, not because it is assumed that the men (and nowadays women) who choose to become military pilots are especially likely to "dump" their IQs, but because military aviation is especially demanding.

Stress can thus be seen as a fourth vector in the model, adding an affective component to the definition of judgment task difficulty (Figure 3).

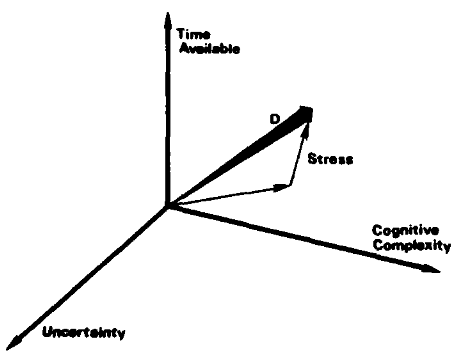


Figure 3: UCT Model: Stress as the Fourth Vector Determining Judgment Task Difficulty (D).

So far, then, two of the four factors likely to influence judgment performance have been discussed. The following conclusions seem warranted:

- Judgment task difficulty can be seen as the resultant vector of cognitive complexity, uncertainty, and the inverse of time availability.
- Stress will affect judgment performance in a non-linear fashion: positively up to an individual maximum, and negatively beyond that. The stress in a situation requiring judgment can be thought of as consisting of three components: the null-level stress or the stress at the point of tasking, stress resulting from the difficulty of the judgment task itself, and stress resulting from the interaction of the flight problem and the background problem.

Types of Judgment Tasks

Before discussing the application of the model, one final distinction should be introduced. It is possible to distinguish between two types of judgment tasks. The first type, Type 1, occurs when the flow of some routine evolution is disturbed by some unpredicted, unforeseen occurrence (such as in an emergency or malfunction), or when something planned and predicted has not occurred (such as when the tanker aircraft does not show up at the planned rendezvous). Many such situations are covered by procedures, emergency and otherwise, but the potential variations in the situations are so innumerable that it would not only be inefficient, but virtually impossible, to invent a procedure for every eventuality.

The second type of judgment tasks are those tasks where the course of events is never routine, never predictable, always uncertain, and where judgment is therefore always required. This type of judgment task may be called a Type 2 task and air combat maneuvering is a perfect example for this class of judgment tasks.

## APPLICATION OF THE MODEL

The two remaining factors, availability of relevant cognitive strategies and availability of relevant affective strategies for dealing with stress, will be discussed in the dual context of selection and training.

Selection

In the selection process for training in the Israeli Air Force, the applicants are subjected not only to paper-and-pencil tests and personality interviews, but also to situational tests which tax an applicant's intellectual resourcefulness and his ability to withstand psychological stress in practical, hands-on situations. It appears that these selection procedures are quite effective and that their effectiveness can be directly understood in view of the preceding discussion. Given the conceptual model above, it would appear possible to design carefully graduated situations varying in cognitive complexity, uncertainty, time availability, and stress that would yield valid predictive scores, when referenced to scores of a norm group of successful pilots.

Training

If the conceptual model presented above is applied to training, one can draw conclusions concerning the validity of current aircrew training methods and one can begin to define new training strategies specifically aimed at the development of good judgment performance under various degrees of psychological stress.

Current military aircrew training is characterized by an emphasis on correct completion of prescribed procedure, compliance with rules, and specific flight techniques. Judgment is a coveted quality and is usually evaluated under such headings as "headwork" or "airmanship", but explicit instruction in headwork or airmanship is almost totally absent.

The author has personally received this type of training in the U.S. Air Force and can attest to its inadequacy based on his rude awakening upon assignment to an operational squadron of the German Luftwaffe. A former colleague of mine and former F-14 instructor pilot, describes current training practices in the Navy as follows:

> "The student is taught from day one, that he must use correct procedures. He is drilled for hours in these procedures and learns to accomplish tasks using the same steps each and every time. Use of checklists to cover normal, abnormal, and emergency procedures is mandatory.
>
> At the same time, he is presented with a myriad of rules to follow. Compliance with Course Rules, Air Traffic Control, NATOPS, SOP, as well as Station, Wing, and NAVAIR instructions is taught.
>
> When reasonably proficient in applicable procedures and rules, the student is taught flying technique and is evaluated on "basic airwork". If the student has an opportunity to exercise judgment, he is evaluated under the heading of "headwork". The system is structured, however, so that virtually no opportunity exists, under normal circumstances, for a student to exercise his judgment. The student will be successful if he follows correct procedures and rules.
>
> Fleet replacement squadrons follow a similar approach to aircrew training. Flight techniques (including weapon system utilization) are more heavily emphasized than procedures or rules as a student is expected to master procedures and rules quickly with a high degree of transfer of knowledge from the Training Command.
>
> Graduates of the present system can be characterized as reasonably competent airmen, well-indoctrinated in applicable procedures and rules, whose decision-making abilities are relatively unknown.
>
> Once in the fleet, the fledgling aviator is expected to learn by example as he flies with an experienced flight leader and/or crewman. When a situation arises requiring exercise of judgment, he can normally count on being assisted by many experienced people, both in the air and on the ground.
>
> Problems arise in this system when the inexperienced aviator is cut off from the decision-making assistance of others. The student has very little to fall back on, except his procedures and rules. Unfortunately, there are not procedures to cover every problem that may arise.
>
> The aviator will probably decide on an acceptable course of action based on his knowledge and the decision-making skills and judgment that he developed prior to Navy flight training..."

When this state of affairs is examined in light of the model and the concepts presented previously, it is obvious that training in Type 1 judgment tasks is totally absent or accidental in two respects: it occurs only by accident, and when it occurs in the air, it is likely to cause an accident. Training in Type 2 judgment tasks exists only in the form of feedback, such as in the ACMR facilities when an air combat maneuvering sortie is replayed in three dimensions and each move and countermove is discussed post-facto.

Is explicit, systematic training of judgment really all that important? After all, the training pipelines do produce aviators who are able to function successfully in peacetime as well as in combat. The counter question here is: "At what cost?" It is well known, from military as well as from civilian accident statistics, that the overwhelming majority of aircraft accidents is attributable to pilot error and that most of these are simply errors in judgment. In other words: waiting for experience to teach you enough judgment can kill you.

Further insight into the importance of explicit and systematic judgment training throughout the pilot's career is gained when comparing jobs which are highly proceduralized by their very nature, such as the job of a bank clerk with the job of a military combat pilot. Figure 4 illustrates the task universes of these two jobs. They are arbitrarily limited to intellectual tasks using Gagné's taxonomy.

This illustration, by the way, is not based on actual data, but rather on sound judgment. The intent is to illustrate a principle rather than to provide exact quantitative data. The fact that the two task universes are different in overall size is irrelevant. What is relevant, however, is the fact that the task universe of the pilot contains much higher proportions of high-level tasks and much higher proportions of judgment tasks, i.e., incidents where tasks must be performed under conditions of uncertainty. There is little doubt in a bank clerk's job, once he has learned his rules and procedures. That is not the case in a pilot's job. When viewed in this light, current training practices essentially provide the pilot with bank clerk training. This is hardly in accordance with the much touted maxim "Train Like You Fight".

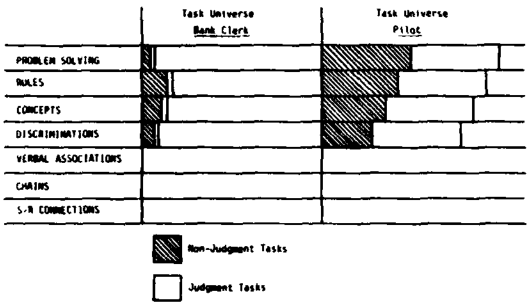


Figure 4. Proportions of Judgment vs. Non-Judgment Tasks in 2 Task Universes.

If a fighter pilot, or any other military pilot for that matter, must have one characteristic, one trait that is absolutely essential in the performance of his duties, that trait is probably initiative (besides judgment). However, trainees who are continuously given directive commentary and who are continually drilled in rigid rules and procedures will hardly develop initiative, but much more likely will abdicate responsibility and await orders. Training in judgment on the other hand, i.e., training under conditions of uncertainty, especially if such training follows an orderly step-by-step course, systematically develops a trainee's self-reliance and with that, his initiative.

One more point should be made regarding the importance of including judgment training in aircrew training curricula. The current rigid regimentation and proceduralization of training frequently leads to actual fear of departing from established procedures. Not all emergency situations fit precisely the case for which a given procedure is designed. As a consequence, the rigidly trained aviator who is unable to and fearful of bending the procedure might end up bending the airplane.

Given these arguments, the next logical question is: "If judgment training is so important, then why is it not included in the average aircrew training curriculum?". Two reasons come to mind. First of all, it is much easier to train overt, observable behavior. This state of affairs has not changed with the advent of ISD. Task analyses and objectives hierarchies for aircrew training rarely contain the covert, higher level cognitive tasks required of the combat pilot.

The second reason is the well known phenomenon where each accident spawns another rule or procedure to be included in the flight manual. The attempt to reduce costly errors due to bad judgment by regulation and proceduralization is like trying to cure the problem by treating the symptoms instead of the causes. In the words of one instructor pilot: "The exercise of judgment is inversely proportional to the amount of regulation. The amount of regulation is usually proportional to the cost of judgment errors." Or, to say it somewhat differently: The attempt to remedy judgment errors by proceduralization starts a vicious circle which only leads to more errors in judgment. The only cure is to train judgment systematically.

## New Training Strategies

The model presented in this paper offers a methodology by which such systematic training can be conceptualized, designed, and implemented.

First of all, judgment training must enable the trainee to distinguish the flight problem from the background problem. As mentioned before, background problems may include such things as medical emergencies, business trips, and lovers. However, they can be considerably more subtle than that. One background problem that the military pilot is especially prone to encounter is excessive machismo, brought about by peer group pressure. This brings to mind a famous Royal Air Force proverb: "There are old pilots and there are bold pilots, but there are no old bold pilots." The "can do" attitude that is especially prevalent in today's Navy, quite likely fosters a scarf-flying, devil-may-care attitude rather than good and sound judgment. Given a behavioral objective such as "The student will identify the background problem, given verbal descriptions of flight scenarios, correctly in x out of y cases," it should not be too difficult to design appropriate instruction. Such instruction would generate in the student an awareness of how the background problem may bias or interfere with his judgment in solving the flight problem.

Secondly, the three-pronged model of uncertainty, cognitive complexity and time availability, allows systematic design of scenarios which are carefully graduated along these three variables. If the student is subjected to successively more difficult judgment problems under gradually increasing psychological stress, and if all such training sequences are administered on the basis of reaching criterion performance before progressing to the next higher level of task difficulty, it would appear reasonable to expect a high degree of training effectiveness.

For example, in any given area of flight instruction, be it familiarization, navigation, air-to-ground tactics, air-to-air tactics, etc., the model allows the design of a variety of possible systematic training strategies which lead from the least difficult to the most difficult of judgment problems. One such possible strategy is presented in Figure 5 in the form of a series of histograms which show relative quantities of the four variables of uncertainty, cognitive complexity, time availability and stress.

As the figure shows, the student is initially presented with scenarios or situations of low cognitive complexity and ample time availability. As he becomes proficient, an element of uncertainty is introduced while keeping complexity and time constant. Gradually, stress is introduced, the time

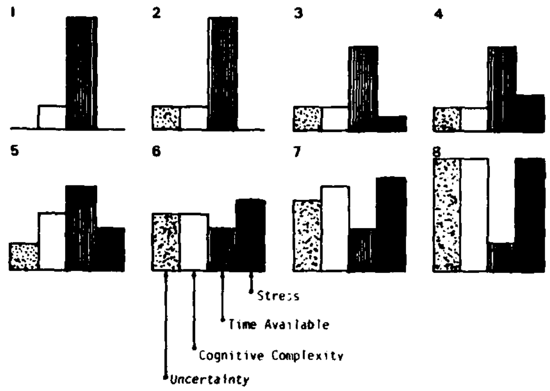


Figure 5. Histogram Representation of an 8-Step Strategy for Judgment Training.

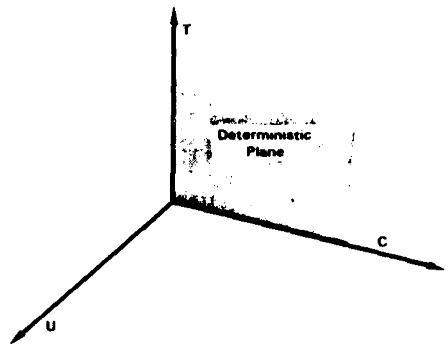


Figure 6. UCT Model: The Deterministic Plane

available is decreased, and the levels of uncertainty and cognitive complexity are built up until the student can finally demonstrate acceptable judgment performance over the entire spectrum of the particular subject matter domain being trained.

The gradual build-up of stress deserves special attention. Classroom instruction, i.e., the academic environment, presents very little natural stress. Stress is somewhat increased when the student transitions from the classroom to the simulator environment, since he is there operating under real-time conditions and under the influence of much more sensory stimulation than in the classroom. The transition from the simulator environment to the flight environment, however, represents a quantum jump in stress. The reason for this is quite simply, fear of death. The simulator cannot crash. It is, therefore, important that the student is accommodated to these higher levels of stress in the preceding simulator and academic environments. It is equally important not to overdo this principle so that the student does not develop fear of flying.

A second note of caution should be introduced here. Current training essentially remains in the deterministic plane (Figure 6). The training situations which are administered are usually canned, and have very little built-in uncertainty. As mentioned previously, the student learns innumerable rules and procedures. On the face of it, it would seem quite reasonable to retain this sort of training and to proceed along the uncertainty axis only after the student has acquired a firm basis in the deterministic plane. One could, for example, use in tactical decision-making, highly complex algorithms that the student works through in a classroom environment. It is doubtful whether training in such deterministic modes of operation has a high degree of transfer to judgment performance which is an essentially different mode of cognitive operation, i.e., a probabilistic mode. Flying will never be totally predictable, and any attempts to transform the pilot into a high-speed automaton or computer are doomed to failure. The development of cognitive strategies that are likely to be successful in an uncertain environment is probably fostered more effectively and efficiently, if uncertainty is introduced all along, i.e., if the student is led along a path which proceeds step-wise along <u>each</u> of the axes.

## Research

The preceding discussion of training design strategies based on the UCT model immediately leads to numerous questions which can only be solved by experimentation. It is suggested that the UCT model is an exceptionally productive conceptual vehicle for the design of research programs because of its face validity on the one hand, and because of the many questions it poses, on the other hand. It appears suitable not only as a vehicle for investigating instructional strategies for judgment training, but also for the investigation of the judgment phenomenon itself. The aircrew training community, however, can hardly afford to wait until the results from such a research program, which would take years to put into motion and years to conduct, are available. Such waiting would only perpetuate the depressing accident statistics on pilot error and endanger the combat readiness of our Armed Forces.

## Beginnings

The aircrew training community has, in fact, already begun to implement new forms of training which are likely to foster the development of good judgment. For example, the F-15 program features situational emergency training. In this program, the old style boldface emergency procedure training is totally absent. The student learns only three rules: 1. maintain aircraft control, 2. analyze the situation and take proper action, and 3. land as soon as practicable. The student is presented with carefully structured scenarios, both in the classroom and the cockpit procedures trainer, and is consistently encouraged to use his judgment in finding the proper action for his problem.

Another example is the air combat training syllabus for the F-14 aircrews, developed by Veda Incorporated. In this syllabus, the pilots are first trained in the classroom in the general principles of maneuvering an F-14 in an air combat situation. They then proceed to the ACMR debriefing facility which is used in a pro-active manner, rather than in the debriefing/feedback mode. The student is there presented with a graphic image of a typical engagement, and on a second screen, with such data as airspeed, altitude, etc., for both the fighter and the opponent. The dynamic graphic presentation is frozen at crucial points, and the students are asked to assess the situation either from the standpoint of the fighter or the opponent, and to exercise their judgment in deciding on their next move. It is quite possible (however, not presently implemented) to create fairly high levels of stress by increasing the pressure for quick answers and by punitive comments for wrong or slow answers. The students then transfer to the simulator environment where they fly the same types of engagements. The simulator of course also offers the advantage of decision time manipulation by the freeze capability. Stress levels again can be manipulated by the manner in which the instructor reacts to the student's actions. The student finally proceeds to the flight environment, well prepared for the split-second judgments he must make under stress. He no longer finds himself thrust suddenly into an environment which, compared to his preceding instruction, shows simultaneously enormously increased levels of uncertainty, complexity and stress, and much less available time. The phenomenon of the IQ dump will hopefully occur with less frequency, but it is as yet too early to tell.

## SUMMARY

In his recently published work, "The Third World War", General Sir John Hackett advances the hypothesis that said world war will be won by--among other things--the higher degree of independence in junior leaders in the tactical area. Such independence requires judgment, good judgment under stress. There can be little doubt about the importance of systematic judgment training not only for aircrews, but throughout the Armed Forces.

This paper suggested a conceptual model and a design approach for systematic judgment training. The ideas presented here, albeit not tested by either experiment or experience, are simple and operational enough to be put into practice immediately.

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# STUDENT FLOW SIMULATION MODEL - APPLIED TO U.S. NAVY CONSOLIDATED ELECTRONIC WARFARE TRAINING SYSTEM

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ABSTRACT

This paper describes an applied training research study in the use of computer simulation being conducted for the Chief of Naval Education and Training (CNET) by the Training Analysis and Evaluation Group (TAEG) in the U.S. Navy. The study is a part of the Consolidated Navy Electronic Warfare School (CNEWS) training system program. A computer simulation model has been developed to model the complex student flows and training resource utilization patterns through a multi-track, mixed group-paced and self-paced training curriculum which exists in the Electronic Warfare School (EW) at the Naval Technical Training Center. This paper also describes the effectiveness of using SLAM as a simulation language to model the network-oriented structure of this simulation.


## I. INTRODUCTION

### Background

The Consolidated Navy Electronic Warfare School (CNEWS) at the Naval Technical Training Center (NAVTECHTRACEN), Corry Station, Pensacola, Florida, conductes basic and advanced operator and maintenance training for 25 types of students, including officers and enlisted, and includes more than 14 separate student pipelines with various combinations of courses of training.

In May 1977, Chief of Naval Education and Training (CNET) assigned TAEG the responsibility for the development of a new consolidated EW operator training curriculum for CNEWS. Once implemented, the new operator training system will provide individualized instruction using a variety of training resources such as programmed instruction; narrative texts, sound-slide programs; random-access, interactive videotape programs; classroom and laboratory instruction; training devices and operational equipment. The curriculum will be managed by means of the Navy's Computer Managed Instruction (CMI) system.

In the new curriculum, all students will not take all learning modules, but will proceed through the respective learning tracks tailored to their specific instructional needs and their next duty assignments. A central component of the EW operator training system will be a 60-student station generalized EW operatory training device, Device 10H1. The device provides computer-aided training in general system familiarization, operator skills development, operating techniques, EW capabilities and limitations and EW watch-standing and tactical exercises.

As the development of the EW operator curriculum progressed, it became apparent that the complexity of the task dictated the need for a management planning tool for CNEWS planners to aid them in early identification of the likely impacts of the new curriculum on the other maintenance and operator training courses currently being taught and those that will continue to be taught at CNEWS after the individualized curriculum is on line.

The problem confronting TAEG and the CNEWS planners is twofold; i.e., (1) providing group-paced instruction in a variety of operator, maintenance, and technology courses using the school's current resources; and, (2) concurrently planning for the development and implementation of Device 10H1 and the development and implementation of the new individualized EW operator curriculum.

Compounding the CNEWS planning problem is the fact that student input rates fluctuate over time. Therefore, the school's operation will have to be periodically adjusted to accommodate increased and decreased student input rates in order to supply adequate quantities and appropriate types of training materials, equipment, media, and training devices (such as an adequate number of student stations for Device 10H1). These adjustments will be necessary to assure smooth student flow through the curriculum in order to meet student output requirements.

Solving the forecasting, planning, scheduling, and resource management problems facing CNEWS planners (significantly complicated by the implementation of the new EW operator curriculum and the introduction of Device 10H1) requires assessment of numerous integrated factors. The character of the problem precludes easy solution by traditional means. This type of problem is, however, ideally suited to solution by computer simulation.

The objective of this study is to develop a user-oriented, predictive computer model of the CNEWS student flow through the various courses in its curriculum. The model should allow the EW planner to manipulate and evaluate various curriculum variables via simulation before committing such approaches to development and implementation.

## II. CONSOLIDATED NAVY ELECTRONIC WARFARE SCHOOL

This section describes CNEWS' current and projected training program. The training program description includes a discussion of student input patterns, EW course descriptions, student flows (tracks) through courses in the curriculum, training facility, media/device/operation equipment utilization patterns, and school training management policies.

Three major types of students attend CNEWS; i.e., officers, enlisted EW's and enlisted person nel from other Navy ratings and other branches of the military. Some civilians and foreign military personnel undergo training at CNEWS, but their number is small, and for purposes of model development, they are not included in this study. In order to describe CNEWS' current and projected training, it is necessary to define the basic terminology and data base elements adopted in the study.

### CNEWS Data Base Elements

The first data area describing CNEWS processes consists of all courses conducted in EW operations, maintenance, and technology. There are four major kinds of operation courses; basic, advanced, watchstanding, and tactical operations as shown in Table 1. Two kinds of maintenance courses are taught; preventive and corrective. There are four kinds of technology courses taught; digital, 3M (Maintenance and Material Management), preventive, and corrective. In addition to general (common-core) courses taught in operations and maintenance training, a number of equipment-specific training courses are also held at CNEWS. The four major equipment-specific areas of training are: AN/WLR-1, AN/WLR-8, AN/SIQ-17, and AN/SLQ-32. Table 2 is a list of the courses taught at CNEWS identified by the type of training, the course title, its length in weeks, and its Course Data Processing (CDP) number.

The Training Track Data portion of the EW student flow model curriculum track process describes significant relationships among the students and the training courses they take at CNEWS for purposes of model design and development. Table 1 also lists these 11 types of data.

A third area of data collected to aid in the development of the model's curriculum track processes includes CNEWS training resources and utilization data. For each course taught at CNEWS, nine major areas of training resource information and utilization patterns were investigated including: (1) classrooms, (2) learning centers (including carrels and associated audiovisual media such as sound/slide projectors, 8 mm film, cassette recorders, videotape players and student responders), (3) laboratories, (4) combination classroom/laboratories, (5) training devices/simulators, (6) operational equipment, (7) student/instructor ratio, (8) student/equipment ratio, and (9) cross-utilization of resources (facilities used by more than one course; e.g., classroom or equipment).

### Current CNEWS Pipelines

The current CNEWS training curriculum for enlisted students, which includes the majority of the students attending the school consists of Basic Operations (CDP 602A) and EW Preventive Maintenance Technology (CDP602B) courses, followed by one of the equipment operations courses as appropriate (AN/WLR-1 (CDP 015A), AN/SLQ-32 (CDP 016A, AN/SLQ-17 (CDP 107A), or AN/WLR-8 (CDP 018A) followed by the appropriate equipment-specific preventive maintenance course. All students then take Advanced Operations (CDP 602D) and then finish their training at CNEWS with one of the appropriate equipment-specific tactical operations courses. The choice of what equipment-specific course students take is determined by their subsequent duty assignments.

In the current CNEWS curriculum, all courses are group-paced (lock-step) except for the Basic Operations course (CDP 602A). The Basic Operations course has recently been developed into individualized (self-paced) programs of instruction. The Basic Operations course (CDP 602A) is significant since most all categories and types of students, officer and enlisted, normally take this course. Figure 1 shows a more detailed diagram of the CNEWS enlisted student flows. It is based upon the data collected and organized in Tables 1 and 2. This figure will also be used in the following discussion to show what changes will occur with the implementation of Device 10H1.

### Proposed CNEWS Pipelines Using Device 10H1

The EW operator curriculum under development for implementation with Device 10H1 will be individualized or self-paced instruction. The major differences between the present group-paced (lock-step) operator curriculum and the individualized curriculum under development are: student self-pacing through each curriculum module, lesson and lesson topic. Each lesson topic is completed by the student in a classroom, a learning center with multimedia learning carrels or a laboratory using one of the student stations of Device 10H1. The learning carrels consist of individual study booths equipped with various combinations of sound/slide equipment and/or random-access, interactive videotape equipment. The student is appropriated support with lesson topic narratives and/or programmed materials or other types of individualized learning materials.

The following lists the CNEWS student tracks and categories, the Device 10H1 operator curricular phases each will take, and the current CNEWS courses that the Device 10H1 operator curriculum phases will replace when the device is ready-for-training and the curriculum has been developed and is in place.

**INPUTS**

Type Students

**OFFICERS**

- VQ - Pilot
- ASW-TACAIR
- EA6 PIPREP
- VQ Eval
- EA6 ECMO
- VAQ 33
- Marine EA6

**ENLISTED EW**

- USN 6YO
- USN 4YO
- USN Late Convertee
- USNR 4X10
- USNR 3X6
- Fleet Returnee (Operator)
- Fleet Returnee (Operator/Maintenance)
- Fleet Returnee ELINT

**ENLISTED (OTHER)**

- CTT ELINT
- CTM
- ETSU
- CTM 6YO
- AVEW
- Marine
- USCG

**CIVILIAN**

**FOREIGN**

**PROCESSES**

Curriculum Tracks

**TRAINING COURSE DATA**

Operations
- Basic
- Advanced
- Watchstanding
- Tactical *

Maintenance
- Preventive
- Corrective

Technology
- Digital
- 3M
- Preventive
- Corrective

Equipment-Specific

WLR-1 WLR-8 SLQ-17 SLQ-32

**TRAINING TRACK DATA**

- Sequence
- Type Instruction
- Convening Period/Frequency
- Capacity
- Attrition/Setback Ratios
- Course Lengths
- Module
- Lessons
- Times-to-Train
- Classroom/Laboratory/Trainer Ratio
- CDP Number

**RESOURCE UTILIZATION DATA**

- Classroom
- Learning Center (Including Media)
- Classroom/Laboratory
- Laboratory
- Operational Equipment
- Training Device/Simulator
- Student/Instructor Ratio
- Student/Equipment Ratio
- Cross-Utilization by Courses

**OUTPUTS**

- Multi-year Requirements for Graduates by Student Type
- Course Operation Reports
- Student Time-To-Train
- Queues

Table 1. Consolidated Navy EW School Student Flow Simulation Data Base Elements

Table 2. CNEWS Courses by CDP Number, Title, and Length

Officer EW Courses

| | CDP Number | Title | Length/Weeks |
|---|---|---|---|
| | 6474 | VQ-Pilot Navigator EW Course (VQ PIREP) | 5 |
| | 6475 | Aviation EW Officers Course (EWO) (ASW/TACAIR)(PIREP) | 3 |
| | 9795 | EA-6B Fleet Replacement Pilot EW Course | 5 |
| | 9797 | Fleet Air Reconnaissance EW Evaluator Course | 18 |
| | 9798 | EA-6B Fleet Replacement NFO ECMO Course | 18 |
| | 9799 | VAQ-33 NFO Fleet EW Support Course | 18 |
| | 9928 | EA-6 Marine Aviation EW Course | 18 |
| | | **ENLISTED EW TECHNICIAN** | |
| **Type Training** | **CDP Number*** | **Course Title** | **Length/Weeks** |
| Basic Operations | 602A | EW Technician Class A School Basic EW Operations | 4 |
| Maintenance and Technology | C1* | Preventive Maintenance Technology | 10 |
| | 015A | AN/WLR-1 Operator-Equipment Operations | 1 |
| | 016A | AN/SLQ-32 Operator-Equipment Operations | 1 |
| | 017A | AN/SLQ-17 Operator-Equipment Operations | 1 |
| | 018A | AN/WLR-8 Operator-Equipment Operations | 1 |
| | 602C | 3M System/Test Equipment Training | 2 |
| | 015B | AN/WLR-1 Operator-Preventive Maint. | 2 |
| | 016B | AN/SLQ-32 Operator-Preventive Maint. | 2 |
| | 017B | AN/SLQ-17 Operator-Preventive Maint. | 2 |
| | 018B | AN/WLR-8 Operator-Preventive Maint. | 2 |
| | C2* | Corrective Maintenance Technology | 5 |
| | C3* | Digital Technology | 4 |
| | 015D | AN/WLR-1 ESM System Maintenance | 11 |
| | 016D | AN/SLQ-32V2 ESM Maintenance-AN/UYK-19 | 3 |
| | 017D | AN/SLQ-17 Maintenance-AN/UYK-20 | 4 |
| | 018D | AN/WLR-8 Maintenance | 11 |
| | 412M | AN/ULQ-6 Maintenance | 4 |
| | 016E | AN/SLQ-32V2 ESM Maintenance-System | 6 |
| | 017E | AN/SLQ-17 Maintenance | 19 |
| | 016F | AN/SLQ-32V3 ECM Maintenance | 3 |
| | 604C | Submarine Electronics Technician EW Technology-Commun./Radar Theory | 3 |
| Advanced Operations | 602D | Advanced EW Operations | 3 |
| | 015C | AN/WLR-1 Operator-Tactical Operations | 2 |
| | 016C | AN/SLQ-32 Operator-Tactical Operations | 2 |
| | 017C | AN/SLQ-17 Operator-Tactical Operations | 2 |
| | 018C | AN/WLR-8 Operator-Tactical Operations | 2 |
| | 3197 | Cryptologic Technician-Field Type 4/Class A (ELINT Operator) | 12 |

*C1,C2,C3 - Multiple CDPs used for these three courses to identify various categories of students attending.

**C1 Preventive Maint. Technology**

- 6029 EW Technician Preventive Maintenance Technology
- 604A Submarine Electronics Technician EW Preventive Maintenance Technology
- 605A Cryptologic Maintenance Technician (CTM) Preventive Maintenance Technology

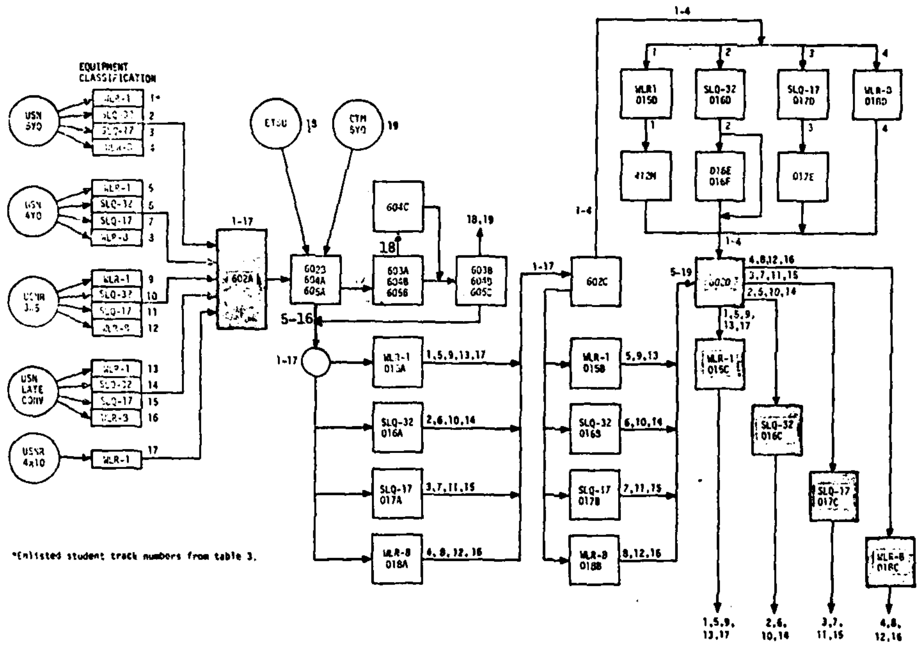
**C2 Corrective Maintenance Technology**

- 603A EW Technician Corrective Maintenance Technology
- 604B Submarine ESM Electronics Technician EW Maintenance Technology
- 605B Cryptologic Maintenance Technician (CTM) Corrective Maintenance Technology

**C3 Digital Technology**

- 603B EW Technician
- 604D Submarine ESM Electronics Technician EW Technology
- 605C Cryptologic Maintenance Technician (CTM) Electronics Technology

Figure 1. CNEWS Student Flow by Tracks and Courses (Part A)




These are shown in Figure 1 with the course boxes shadowed.

| Current CNEWS Course | Replaced By |
|---|---|
| CDP 602A Basic Operations | Device 10H1 Phase I |
| CDP 602D Advanced Operations | *Device 10H1 Phase II* |
| CDP 015C AN/WLR-1 Tactical Operations | |
| CDP 016C AN/SLQ-32 Tactical Operations | |
| CDP 017C AN/SLQ-17 Tactical Operations | Device 10H1 Phase III |
| CDP 018C AN/SLQ-17 Tactical Operations | |

In phase I (basic operations), students will complete a series of academic or off-line (non-10H1) modules in learning centers and then receive a series of modules and lesson topics using Device 10H1 to complete that portion of the curriculum. The basic operations phase of the individualized curriculum using Device 10H1 is planned to be common-core; i.e., each category of student, officer and enlisted, will take the phase I courses.

Phase II (advanced operations) of the Device 10H1 curriculum which will consist of a series of six modules and a number of lesson topics with the number of hours each student is estimated to spend in the learning centers and Device 10H1. Unlike the phase I student traffic flow, the student's path through phase II will consist of first a series of sessions in the learning center for each module and then a number of hours of training on Device 10H1. As a student completes each module in Device 10H1, he will proceed to the next assigned module taking a series of lesson topics in the learning center followed by an appropriate number of hours or lesson topics in Device 10H1 until that module is complete.

When the student reaches phase III (watchstanding and tactical operations) in Device 10H1, his training will become more equipment- or suite-oriented and will consist of two parts. Part A of phase III consists of exercises to orient the student to the type of equipment he will operate in his duty assignment. Part B of phase III consists of a series of exercises or lesson topics in the form of mission scenarios using the equipment suite he used in Part A of phase III. Student flow through phase III will consist of a series of hours of training in Device 10H1 in parts A and B on the respective EW equipment suite modules and lesson topics appropriate for his military specialty and/or next duty assignment.

## III. SIMULATION MODEL DESIGN ELEMENTS

The purpose of this section is to describe the structure of the EW student flow simulation model and its design elements. The first part of the section discusses the level of detail and the design alternatives to be included in the model, followed by a description of SLAM modeling concept and its operational characteristics.

### Level of Details to be Obtained From the Model

The objective of the model is to account for each different type of student in the various pipelines, whether they be in group-paced or individualized training courses, and gather statistical data on each student in order to determine the CNEWS resource utilization patterns, as well as to identify likely problem areas such as student queues or excessive waiting times. In particular, the student flow simulation model will be designed to produce the following types of information.

1. The maximum, minimum, and mean expected times-to-train for each type student

pipeline in the CNEWS curriculum as defined in section II.
2. Identification and definition of classroom/learning center/training device on equipment resource demand situations for the courses in the CNEWS curriculum over a multi-year planning horizon.
3. Identification and definition of training resource/facility requirements to achieve a smooth flow of students through the CNEWS curriculum including group-paced and individualized courses of instruction in terms of existing school capacity and planned capacity. Major variables to be considered include:
   a. the number and types of students and their arrival patterns,
   b. course convening frequency,
   c. instructional materials, media, training devices, and/or operational equipment.
4. Determination of the impact to the school in terms of:
   a. changes in student input distribution and on-board arrival times,
   b. the addition of new instructional resources such as audio-visual equipment, learning carrels, or training devices such as Device 10H1,
   c. the incremental conversion of courses in a curriculum from group-paced to individualized training and in some cases establishment of common-core training.

Description of Design Alternatives

The model will be developed in seven increments in order to be able to determine the impacts of implementing the three phases of the Device 10H1 curriculum. The model will be developed in the following increments:
1. CNEWS Current Operator and Maintenance Curriculum (No Device 10H1),
2. CNEWS Current Curriculum With Device 10H1 Phase I (Basic Operations) Implemented and Replacing Existing Basic Operations Course,
3. CNEWS Current Curriculum With Device 10H1 Phase II (Advanced Operations) Implemented and Replacing Existing Advanced Operations Courses,
4. CNEWS Current Curriculum With Device 10H1 Phase III (Watchstanding-Tactical Operations) Implemented and Replacing Existing Tactical Operations Courses,
5. CNEWS Current Curriculum With Device 10H1 Phases I and II Implemented and Replacing Existing Basic and Advanced Operations Courses,
6. CNEWS Current Curriculum With Device 10H1 Phases I and III Implemented and Replacing Existing Basic and Tactical Operations Courses,
7. CNEWS Current Curriculum With Device 10H1 Phases II and III Implemented and Replacing Existing Advanced and Tactical Operations Courses,
8. CNEWS Current Curriculum With Device 10H1 Phases I, II, and III Implemented and Replacing Existing Basic, Advanced, and Tactical Operations Courses.

Modeling With SLAM

After the specific model-building process had been defined and the structure of the problem specified as discussed, the next step was to select an appropriate simulation language with which to model the decision problem.

SLAM (2) was a simulation language selected for modeling the system. The language allows systems to be viewed from a process, event and state variable standpoint. The authors of SLAM claim that the language combines these modeling philosophies in a unified systems modeling framework.

In SLAM, a discrete change system can be modeled within an event orientation, process orientation or both. Continuous change systems can be modeled using either differential or difference equations. Combined discrete-continuous change systems can be modeled by combining the event and/or process orientation with the continuous orientation. In addition, SLAM incorporates a number of features which correspond to the activity scanning orientation.

Figure 2 presents an overview of the components involved in a SLAM systems analysis. Using the SLAM symbol set provided in (2), the analyst brings to the systems analysis a knowledge of the system and the scenarios to be evaluated. In our modeling the process orientation of SLAM is most important. The process orientation of SLAM employs a network structure comprised of specialized symbols called nodes and branches in a manner similar to Q-GERT. These symbols model elements in a process such as queues, servers and decision points. Based on the scenarios and the purpose for the model building the modeling task consists of combining these symbols into a network model which pictorially represents the system of interest. In short, a network is a pictorial representation of a process. The entities in the system (such as people and items) fow through the network model. The pictorial representation of the system is transcribed by the modeler into an equivalent statement model for input to the SLAM processor.

After the data base file has been created and updated, then the user brings the SLAM model online and links the data base file to the SLAM model. Upon completion of this linkage operation, the user then calls the SLAM processor to interpret the SLAM source program in the FORTRAN compiler and to execute the program. Upon completion of the simulation, a standard SLAM summary report containing all the important statistical observations is automatically provided. The output format designed in a SLAM summary report, however, is general in nature. It will be necessary to redesign the output format tailored to the user's easy-to-read format. Further, a statistical output analysis routine will be created to validate any statistical significance of observations made in the simulation.

IV. EW STUDENT FLOW SIMULATION MODEL FEATURES

This section describes the operational features of the EW student flow simulation model. The first part of this section presents data files created to run the simulation model. The second part of this section discusses typical statistical output features from the model.

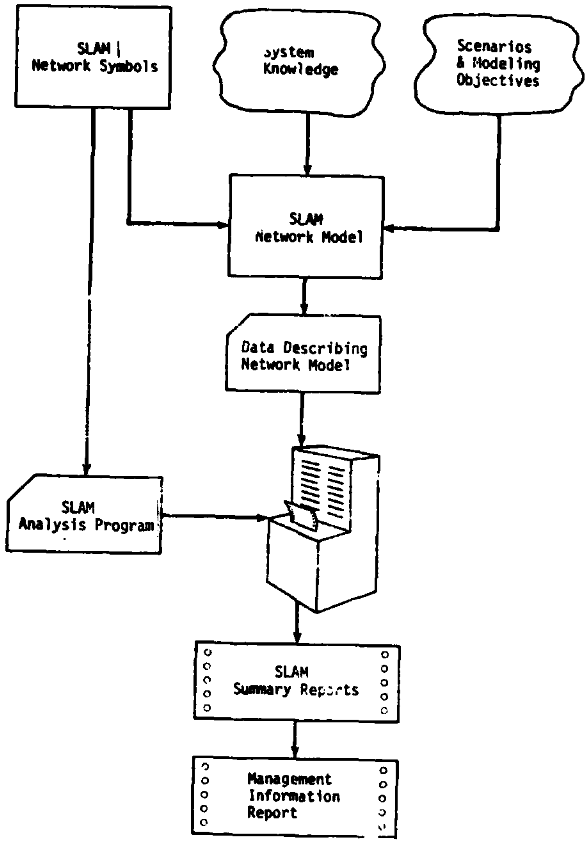



Figure 2. Components of SLAM Model

Description of Model Data Base

The user first interfaces with the Course Data Base module which creates and maintains the course statistics described in the previous sections. The Course Data Base module consists of the five subfile elements - 10H1 Status profile, Instructor profile, Facility profile, Course Description profile, and Input Student Population profile. That is, the Course Data Base is a collection of training course records which provide data required for operation of the simulation model. The specific data elements required in each submodule are illustrated in Figure 3; a further explanation follows.

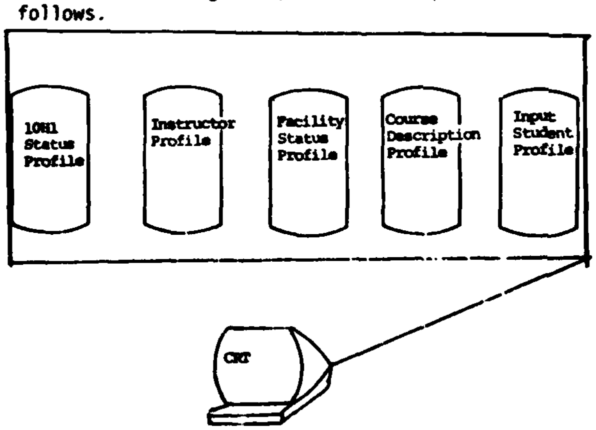



Figure 3. File Elements of Course Data Base

1. Device 10H1 Profile. This file basically contains data elements which describe the transition phase from group-paced courses in the CNEWS curriculum to individualized training courses using Device 10H1. Eight configurations of the transition are included in the profile:

- Device 10H1 is not used.
- Device 10H1 is used for Phase I (Basic Operations) only.
- Device 10H1 is used for Phase II (Advanced Operations) only.
- Device 10H1 is used for Phase III (Tactical Operations and Watchstanding Exercises).
- Device 10H1 is used for both Phases I and II.
- Device 10H1 is used for both Phases I and III.
- Device 10H1 is used for both Phase II and III.
- Device 10H1 is used for both Phases I, II, and III.

By identifying the use of Device 10H1 with an appropriate function code, the student flow simulation model will automatically assume the proper transition phase from group-paced courses to individualized training courses. Therefore, the user does not have to look into the simulation model to verify any changes to be made every time he runs a different set of 10H1 transition phases.

2. Instructor Profile. The instructor profile file is designed to store and update the number and types of instructors available to each course at the time the simulation run is made. As the Course Data Processing (CDP) code is a unique identifier in the Navy, the code is used in the model as the key for instructor identification. The number and type of instructors available to each course are thus entered into the file according to CDP code. Whenever more than one CDP code represents the same course utilization, a new CDP code is created so that cross utilization of the same course by different types of students can be identified.

3. Facility Status Profile. The facility status file will contain only data elements such as various training devices, classrooms and lab equipment which describe the current or anticipated status of various instructional resources available for individualized (self-paced) training courses. Since any changes in the use of instructional resources used for group-paced courses affect only class size and/or course length variables, there is no need to consider these factors explicitly in this simulation.

4. Course Description Profile. The course description file contains the various course statistics required for use during the simulation. Specific input course data elements to be keyed in the file according to CDP code will include: the course length, the class size (for group-paced courses only), the course convening frequency (grouped-paced courses only), and the student course attrition and setback rates.

For individualized courses, the course lengths will depend upon the individual student's performance. Thus, estimates of the minimum, maximum, and average times-to-complete for each course by the students will be required as inputs to the model instead of a single course length figure, as with group-paced courses.

5. Input Student Distribution Profile. The input student distribution profile maintains data elements regarding planned student inputs for each category of student. The projected number and onboard time of arrival at the school for each category of student flowing through the CNEWS curriculum will be used in the simulation model.

Description of the Model's Outputs

The model's outputs derived from its inputs and process interactions are provided in the following case study to demonstrate the effectiveness of using SLAM as a simulation language. The specific assumptions being made in the case study model are:

a. The design alternative assummed was the case of CNEWS current curriculum with Device 10H1 used for Phase I (CDP 602A) only.
b. Seven different types of enlisted EW students were considered with 27 different individual courses. The basic structure of the model was based upon the student flow model described in Figure 1.
c. When courses are convened on the basis of group-paced instruction, provisions were made to open up multiple sessions to reduce the students' waiting times. A policy was set up to convene a course on a regular basis. The minimum and maximum class sizes were established for convening each course.
d. A student setback and attrition problem associated with each course was incorporated in the model. The detailed input data descriptions are given in (1).

Assumming 400-student annual inputs to the model over the two-year period, the following specific outputs can be obtained.

1. Number of Students Graduated Per Course Per Period of Run

Table 4 shows the first category of statistics for variables based upon observations. For this model, these statistics were collected by the network model and include the interval statistics for average class size for each course and training time for each type of student. The first column in Table 3 represents designations of classes and student training tracks. In particular the following information can be obtained by reading down the columns and rows from the table.

a. Average number of students per class.
b. Standard deviation of number of students per class.
c. Coefficient of variation of number of students per class.
d. Minimum number of students in a class over a period of simulation.
e. Maximum number of students in a class over a period of simulation.
f. Number of classes for each type of course that has met over period.
g. Completion time for each type of student per course over period.
h. Total number of students who dropped from courses over period of simulation.

It is seen from Table 3 that the average time in the training system for the USN 6YO was 64.67 weeks with a standard deviation of 9.394 weeks and times ranged from 41.16 weeks and 86.07 weeks. The distribution for time in the system is depicted by the histogram generated by SLAM and shown in Figure 4. There were a total of 49 observations which means that forty-nine students of USN 6YO completed the curriculum over the two-year training period.

Another statistic of interest is the class size of each course and number of class convening frequency. For this example, NUM STUD S C602 in Table 3 stands for the class size of CDP 602C when it was offered on the basis of single session whereas NUM STUD D C602 does when it was offered on the basis of parallel double sessions. The average class size for a single session was 8.5 students with a standard deviation of .7071 students. The size of class was ranged from 8 to 10 students. There were 10 single session offerings over the two-year period.

Courses 016F, 017D, 017E, and 018D were not convened because there were not enough students to take those courses during the simulation period. These facts are identified in the simulation output by "NO VALUES RECORDED".

2. Course Waiting Times

The second category of statistics for this example is the file statistics. Table 4 illustrates course waiting statistics collected from the course files. The specific file numbers in column 1 correspond to course numbers assigned in the network model. The rest of the columns represent the following pieces of information collected over time of model run.

a. The average number of students in the file over time.
b. The standard deviation of the number of entities in the file over time.
c. The maximum number of students in the file at any one time.
d. The current number of students in the file.
e. The average waiting time in the file.

For this example, File No. 1 represents the number of students waiting for course convening of CDP 602A. Thus, the average number of students waiting for CDP 602A was 6.6343, with a standard deviation of 4.8032 students, a maximum of 20 students waited and at the end of simulation there were 17 students in the queue. Finally, the average waiting time by the students was 0.8917 weeks.

## Table 3. Statistics for Variables Based on Observation

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT TRAINING SIMULATION BY SIMDAY SLAM

DATE 1/27/1990 RUN NUMBER 1 OF 1

CURRENT TIME 0,1500E 03
STATISTICAL ARRAYS CLEARED AT TIME 0,5000E 02

**STATISTICS FOR VARIABLES BASED ON OBSERVATION**

| | MEAN VALUE | STANDARD DEVIATION | COEFF. OF VARIATION | MINIMUM VALUE | MAXIMUM VALUE | NUMBER OF OBSERVATIONS |
|---|---|---|---|---|---|---|
| NUM STUD SC1 | 0,9333E 01 | 0,8165E 00 | 0,8748E-01 | 0,8000E 01 | 0,1000E 02 | 6 |
| NUM STUD DC1 | 0,7675E 01 | 0,1541E 01 | 0,2020E 00 | 0,5500E 01 | 0,1000E 02 | 46 |
| NUM STUD SC2 | 0,7200E 01 | 0,7678E 00 | 0,1066E 00 | 0,6000E 01 | 0,8000E 01 | 70 |
| NUM STUD DC2 | 0,5412E 01 | 0,1034E 01 | 0,1911E 00 | 0,4500E 01 | 0,8000E 01 | 17 |
| NUM STUD C604 | 0,4609E 01 | 0,8388E 00 | 0,1820E 00 | 0,2000E 01 | 0,5000E 01 | 23 |
| NUM STUD SC3 | 0,7364E 01 | 0,8091E 00 | 0,1099E 00 | 0,6000E 01 | 0,8000E 01 | 11 |
| NUM STUD DC3 | 0,6529E 01 | 0,1152E 01 | 0,1764E 00 | 0,4500E 01 | 0,8000E 01 | 17 |
| NUM STUD SA15 | 0,7000E 01 | 0,8660E 00 | 0,1237E 00 | 0,6000E 01 | 0,8000E 01 | 17 |
| NUM STUD UA15 | 0,5500E 01 | 0,1049E 01 | 0,1907E 00 | 0,4500E 01 | 0,7500E 01 | 6 |
| NUM STUD A16 | 0,7091E 01 | 0,9439E 00 | 0,1331E 00 | 0,6000E 01 | 0,8000E 01 | 11 |
| NUM STUD A17 | 0,6800E 01 | 0,7888E 00 | 0,1160E 00 | 0,6000E 01 | 0,8000E 01 | 10 |
| NUM STUD A18 | 0,7091E 01 | 0,8312E 00 | 0,1172E 00 | 0,6000E 01 | 0,8000E 01 | 11 |
| NUM STUD S C602 | 0,8500E 01 | 0,7071E 00 | 0,8319E-01 | 0,8000E 01 | 0,1000E 02 | 10 |
| NUM STUD D C602 | 0,8109E 01 | 0,1522E 01 | 0,1877E 00 | 0,5500E 01 | 0,1000E 02 | 23 |
| NUM STUD B015 | 0,1120E 02 | 0,8367E 00 | 0,7470E-01 | 0,1000E 02 | 0,1200E 02 | 5 |
| NUM STUD B016 | 0,1000E 02 | 0,0000E 00 | 0,0000E 00 | 0,1000E 02 | 0,1000E 02 | 6 |
| NUM STUD B017 | 0,1000E 02 | 0,0000E 00 | 0,0000E 00 | 0,1000E 02 | 0,1000E 02 | 6 |
| NUM STUD B018 | 0,9250E 01 | 0,1035E 01 | 0,1119E 00 | 0,8000E 01 | 0,1000E 02 | 8 |
| NUM STUD D015 | 0,1117E 02 | 0,1030E 01 | 0,9223E-01 | 0,1000E 02 | 0,1200E 02 | 12 |
| NUM STUD M412 | 0,1120E 02 | 0,9189E 00 | 0,8205E-01 | 0,1000E 02 | 0,1200E 02 | 10 |
| NUM STUD D016 | 0,6500E 01 | 0,7071E 00 | 0,1088E 00 | 0,6000E 01 | 0,7000E 01 | 2 |
| NUM STUD E016 | 0,8000E 01 | 0,0000E 00 | 0,0000E 00 | 0,8000E 01 | 0,8000E 01 | 1 |
| NUM STUD F016 | | NO VALUES RECORDED | | | | |
| NUM STUD D017 | | NO VALUES RECORDED | | | | |
| NUM STUD E017 | | NO VALUES RECORDED | | | | |
| NUM STUD D018 | | NO VALUES RECORDED | | | | |
| NUM STUD SD602 | 0,9500E 01 | 0,9258E 00 | 0,9745E-01 | 0,8000E 01 | 0,1000E 02 | 8 |
| NUM STUD UD602 | 0,9038E 01 | 0,1266E 01 | 0,1401E 00 | 0,6500E 01 | 0,1000E 02 | 13 |
| NUM STUD C015 | 0,7429E 01 | 0,8106E 00 | 0,1091E 00 | 0,6000E 01 | 0,8000E 01 | 21 |
| NUM STUD C016 | 0,7400E 01 | 0,9661E 00 | 0,1306E 00 | 0,6000E 01 | 0,8000E 01 | 10 |
| NUM STUD C017 | 0,7556E 01 | 0,8819E 00 | 0,1167E 00 | 0,6000E 01 | 0,8000E 01 | 9 |
| NUM STUD C018 | 0,7400E 01 | 0,9661E 00 | 0,1306E 00 | 0,6000E 01 | 0,8000E 01 | 10 |
| TIME USN6YO | 0,6467E 02 | 0,9394E 01 | 0,1453E 00 | 0,4116E 02 | 0,8607E 02 | 49 |
| TIME USN 4YO | 0,4637E 02 | 0,9327E 01 | 0,2012E 00 | 0,2583E 02 | 0,8132E 02 | 87 |
| TIME USNP 3X6 | 0,4362E 02 | 0,8355E 01 | 0,1915E 00 | 0,2626E 02 | 0,6442E 02 | 90 |
| TIME L[illegible] CONV | 0,4485E 02 | 0,8336E 01 | 0,1859E 00 | 0,2733E 02 | 0,6537E 02 | 89 |
| TIME USNR 4X10 | 0,5381E 02 | 0,7959E 01 | 0,1479E 00 | 0,4260E 02 | 0,7663E 02 | 39 |
| TIME SYS ETSU | 0,2347E 02 | 0,3601E 01 | 0,1534E 00 | 0,2004E 02 | 0,3792E 02 | 77 |
| TIME SYS CTM6YO | 0,3064E 02 | 0,7757E 01 | 0,2532E 00 | 0,2409E 02 | 0,6710E 02 | 97 |
| DROP OUT STUD | 0,1920E 02 | 0,1178E 02 | 0,6135E 00 | 0,3055E 01 | 0,6869E 02 | 156 |

**HISTOGRAM NUMBER 33**

TIME USN6YO

| OBSV FREQ | RELA FREQ | CUML FREQ | UPPER CELL LIMIT |
|---|---|---|---|
| 1 | 0.020 | 0,020 | 0.4500E 02 |
| 0 | 0.000 | 0,020 | 0.4600E 02 |
| 0 | 0.000 | 0,020 | 0.4700E 02 |
| 2 | 0.041 | 0,061 | 0.4800E 02 |
| 1 | 0.020 | 0,082 | 0.4900E 02 |
| 0 | 0.000 | 0,082 | 0.5000E 02 |
| 0 | 0.000 | 0,082 | 0.5100E 02 |
| 0 | 0.000 | 0,082 | 0.5200E 02 |
| 1 | 0.020 | 0,102 | 0.5300E 02 |
| 2 | 0.041 | 0,143 | 0.5400E 02 |
| 1 | 0.020 | 0,163 | 0.5500E 02 |
| 1 | 0.020 | 0,184 | 0.5600E 02 |
| 1 | 0.020 | 0,204 | 0.5700E 02 |
| 0 | 0.000 | 0,204 | 0.5800E 02 |
| 1 | 0.020 | 0,224 | 0.5900E 02 |
| 3 | 0.061 | 0,286 | 0.6000E 02 |
| 0 | 0.000 | 0,286 | 0.6100E 02 |
| 4 | 0.082 | 0,367 | 0.6200E 02 |
| 3 | 0.061 | 0,429 | 0.6300E 02 |
| 1 | 0.020 | 0,449 | 0.6400E 02 |
| 2 | 0.041 | 0,490 | 0.6500E 02 |
| 3 | 0.061 | 0,551 | 0.6600E 02 |
| 0 | 0.000 | 0,551 | 0.6700E 02 |
| 6 | 0.122 | 0,671 | 0.6800E 02 |
| 2 | 0.041 | 0,714 | 0.6900E 02 |
| 0 | 0.000 | 0,714 | 0.7000E 02 |
| 3 | 0.061 | 0,776 | 0.7100E 02 |
| 2 | 0.041 | 0,816 | 0.7200E 02 |
| 0 | 0.000 | 0,816 | 0.7300E 02 |
| 1 | 0.020 | 0,837 | 0.7400E 02 |
| 0 | 0.000 | 0,837 | 0.7500E 02 |
| 2 | 0.041 | 0,878 | 0.7600E 02 |
| 1 | 0.020 | 0,898 | 0.7700E 02 |
| 0 | 0.000 | 0,898 | 0.7800E 02 |
| 3 | 0.061 | 0,959 | 0.7900E 02 |
| 0 | 0.000 | 0,959 | 0.8000E 02 |
| 1 | 0.020 | 0,980 | 0.8100E 02 |
| 0 | 0.000 | 0,980 | 0.8200E 02 |
| 0 | 0.000 | 0,980 | 0.8300E 02 |
| 0 | 0.000 | 0,980 | 0.8400E 02 |
| 0 | 0.000 | 0,980 | 0.8500E 02 |
| 0 | 0.000 | 0,980 | 0.8600E 02 |
| 1 | 0.020 | 1,000 | 0.8700E 02 |
| 0 | 0.000 | 1,000 | 0.8800E 02 |
| 0 | 0.000 | 1,000 | 0.8900E 02 |
| 0 | 0.000 | 1,000 | 0.9000E 02 |
| 0 | 0.000 | 1,000 | 0.9100E 02 |
| 0 | 0.000 | 1,000 | 0.9200E 02 |
| 0 | 0.000 | 1,000 | 0.9300E 02 |
| 0 | 0.000 | 1,000 | 0.9400E 02 |
| 0 | 0.000 | 1,000 | 0.9500E 02 |
| 0 | 0.000 | 1,000 | 0.9600E 02 |
| 0 | 0.000 | 1,000 | 0.9700E 02 |
| 0 | 0.000 | 1,000 | 0.9800E 02 |
| 0 | 0.000 | 1,000 | 0.9900E 02 |
| 0 | 0.000 | 1,000 | 0.1000E 03 |
| 0 | 0.000 | 1,000 | INF |
| 49 | | | |

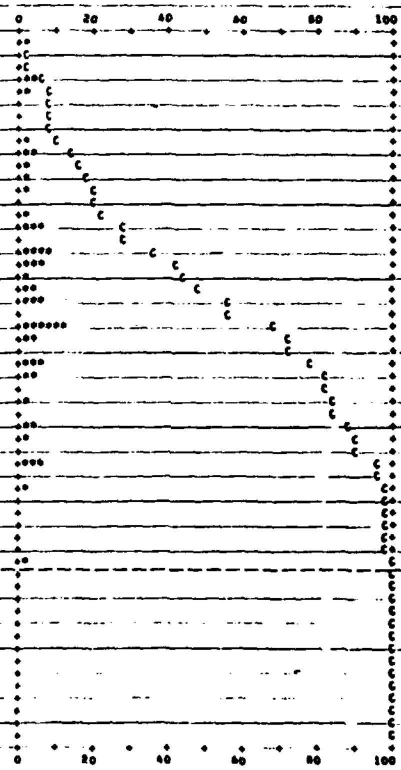



Figure 4. A Sample Histogram for Training Time Variable of the USN GYO.

Table 4. File Statistics for Course Waiting Times

**FILE STATISTICS**

| FILE NUMBER | ASSOCIATED NODE TYPE | AVERAGE LENGTH | STANDARD DEVIATION | MAXIMUM LENGTH | CURRENT LENGTH | AVERAGE WAITING TIME |
|---|---|---|---|---|---|---|
| 1 | AWAIT | 6.6343 | 4.8022 | 20 | 17 | 0.4917 |
| 2 | AWAIT | 1.3000 | 1.9349 | 16 | 5 | 0.3904 |
| 3 | AWAIT | 2.7110 | 2.2457 | 5 | 2 | 2.5102 |
| 4 | AWAIT | 4.1071 | 4.5159 | 16 | 0 | 1.3535 |
| 5 | AWAIT | 1.6357 | 1.9549 | 15 | 0 | 0.8842 |
| 6 | AWAIT | 2.9941 | 2.1677 | 8 | 7 | 3.9225 |
| 7 | AWAIT | 2.8206 | 2.1219 | 8 | 4 | 3.9175 |
| 8 | AWAIT | 2.8147 | 2.1234 | 8 | 4 | 3.4325 |
| 9 | AWAIT | 4.4842 | 5.8303 | 20 | 7 | 0.9443 |
| 10 | AWAIT | 5.7905 | 2.9642 | 12 | 5 | 9.4926 |
| 11 | AWAIT | 5.4658 | 2.9891 | 10 | 6 | 8.2815 |
| 12 | AWAIT | 5.1618 | 3.4198 | 10 | 4 | 8.0653 |
| 13 | AWAIT | 4.8530 | 3.8635 | 10 | 7 | 5.9913 |
| 14 | AWAIT | 3.1952 | 2.9273 | 12 | 3 | 2.3322 |
| 15 | AWAIT | 4.8611 | 4.4206 | 12 | 0 | 4.3403 |
| 16 | AWAIT | 2.0209 | 1.5039 | 7 | 2 | 13.4727 |
| 17 | AWAIT | 1.6001 | 2.0592 | 6 | 0 | 20.0010 |
| 18 | AWAIT | 0.0000 | 0.0000 | 0 | 0 | 0.0000 |
| 19 | AWAIT | 0.6771 | 0.4669 | 1 | 1 | 67.9100 |
| 20 | AWAIT | 0.0000 | 0.0000 | 0 | 0 | 0.0000 |
| 21 | AWAIT | 0.0000 | 0.0000 | 0 | 0 | 0.0000 |
| 22 | AWAIT | 2.7697 | 3.9102 | 20 | 5 | 0.8765 |
| 23 | AWAIT | 1.9759 | 1.7463 | 8 | 1 | 1.2585 |
| 24 | AWAIT | 3.5787 | 2.9174 | 8 | 0 | 4.8361 |
| 25 | AWAIT | 3.2578 | 2.7349 | 8 | 2 | 4.6540 |
| 26 | AWAIT | 2.0896 | 2.8100 | 8 | 2 | 2.7495 |
| 27 | AWAIT | 0.0000 | 0.0000 | 1 | 0 | 0.0000 |

3. Course Utilization Statistics

The third category of statistics for this example is statistics on regular activities. The activity index in Table 5 presents various activities associated with training course curriculum. In particular, the following statistics can be observed from the table over the two-year simulation period.

a. The average number of students undertaking the activity.
b. The standard deviation of the number of students undertaking the activity over time.
c. The maximum number of students undertaking the activity at any one time.
d. The number of students which have completed the activity.

For this example, the activity number 1 in the first column in Table 5 represents the course utilization statistics for CDP 602A. The results show that 542 students completed the course during the two-year time units of simulation, and that there was an average of 21.6248 students in transit between the 602A and the C1 (see Figure 1). The maximum number of students undertaking the course at any one time was 36. There are currently 24 students taking the course at the end of simulation run.

4. Resource Activity By Type of Training Facility (Device 10H1).

The last category of statistics for this example is statistics on service activities. Recall that Device 10H1 was used to convert CDP 602A into a Self-paced instructional system. Thus, Table 6 summarizes resource utilization statistics for Device 10H1. For example, the following pieces of information can be obtained.

a. The current capacity of the resource (Device 10H1).
b. The average utilization of the resource over time.

Table 5. Course Utilization Statistics

**REGULAR ACTIVITY STATISTICS**

| ACTIVITY INDEX | AVERAGE UTILIZATION | STANDARD DEVIATION | MAXIMUM UTILIZATION | CURRENT UTILIZATION | ENTITY COUNT |
|---|---|---|---|---|---|
| 50 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 51 | 0.2600 | 0.4386 | 1 | 1 | 13 |
| 52 | 0.1003 | 0.3004 | 1 | 0 | 3 |
| 53 | 0.4404 | 0.4964 | 1 | 0 | 23 |
| 54 | 0.5400 | 0.4944 | 1 | 0 | 27 |
| 55 | 0.6596 | 0.4739 | 1 | 1 | 21 |
| 56 | 0.7000 | 0.4583 | 1 | 1 | 23 |
| 57 | 0.6700 | 0.4702 | 1 | 1 | 22 |
| 58 | 0.3400 | 0.4737 | 1 | 0 | 17 |
| 59 | 0.9000 | 0.3000 | 1 | 1 | 45 |
| 60 | 0.4591 | 0.4983 | 1 | 1 | 9 |
| 61 | 0.4591 | 0.4983 | 1 | 1 | 5 |
| 62 | 0.3400 | 0.4800 | 1 | 1 | 4 |
| 63 | 0.7600 | 0.4271 | 1 | 1 | 38 |
| 64 | 0.6210 | 0.4851 | 1 | 0 | 16 |
| 65 | 0.8400 | 0.3666 | 1 | 1 | 10 |
| 66 | 0.9410 | 0.2357 | 1 | 0 | 12 |
| 67 | 1.0000 | 0.0000 | 1 | 1 | 12 |
| 68 | 1.0000 | 0.0000 | 1 | 1 | 12 |
| 69 | 1.0000 | 0.0000 | 1 | 1 | 12 |
| 70 | 1.0000 | 0.0000 | 1 | 1 | 18 |
| 71 | 0.5787 | 0.4938 | 1 | 1 | 28 |
| 72 | 0.7900 | 0.4073 | 1 | 1 | 70 |
| 73 | 0.6215 | 0.4850 | 1 | 0 | 16 |
| 74 | 0.6400 | 0.4800 | 1 | 1 | 16 |
| 45 | 0.5783 | 0.4936 | 1 | 1 | 14 |
| 1 | 21.6248 | 4.6531 | 36 | 24 | 542 |
| 75 | 0.0900 | 0.4906 | 4 | 0 | 9 |
| 2 | 72.6994 | 6.6403 | 87 | 77 | 322 |
| 76 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 3 | 16.4000 | 3.8566 | 31 | 0 | 328 |
| 77 | 2.4400 | 3.4450 | 11 | 0 | 122 |
| 4 | 3.1245 | 2.2526 | 5 | 1 | 101 |
| 78 | 0.0900 | 0.6104 | 6 | 0 | 8 |
| 5 | 11.8548 | 4.9339 | 25 | 20 | 290 |
| 79 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 6 | 1.8500 | 3.5366 | 15 | 0 | 185 |
| 80 | 0.0600 | 0.3394 | 3 | 0 | 6 |
| 7 | 0.7800 | 2.2387 | 8 | 0 | 78 |
| 81 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 8 | 0.6800 | 2.0537 | 8 | 0 | 68 |
| 82 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 9 | 0.7800 | 2.2342 | 8 | 0 | 78 |
| 83 | 0.3500 | 1.2570 | 8 | 0 | 35 |
| 10 | 4.1690 | 7.4687 | 20 | 0 | 446 |
| 84 | 0.0100 | 0.0995 | 1 | 0 | 1 |
| 11 | 1.1200 | 3.3683 | 12 | 0 | 56 |
| 85 | 0.5500 | 1.1169 | 4 | 0 | 55 |
| 12 | 1.2083 | 3.2580 | 10 | 0 | 49 |
| 86 | 0.4000 | 0.9381 | 4 | 0 | 40 |
| 13 | 1.2093 | 3.2603 | 10 | 0 | 70 |
| 87 | 0.7500 | 1.6456 | 8 | 0 | 75 |
| 14 | 1.4800 | 3.4132 | 10 | 0 | 74 |
| 49 | 0.1100 | 0.5458 | 4 | 0 | 11 |
| 15 | 14.7400 | 6.2460 | 32 | 12 | 134 |
| 88 | 0.5800 | 1.9400 | 9 | 0 | 58 |
| 16 | 4.2705 | 5.4707 | 12 | 10 | 102 |
| 89 | 0.0000 | 0.0000 | 0 | 0 | 0 |
| 17 | 0.3900 | 1.5485 | 7 | 0 | 13 |
| | 0.0000 | 0.0000 | 0 | 0 | 0 |
| | [illegible] | 1.6853 | 8 | 0 | 0 |
| | | 0.0000 | 0 | 0 | 0 |
| | | 0.0000 | 0 | 0 | 0 |
| | | [illegible] | 0 | 0 | 0 |
| | | | 0 | 0 | 0 |

c. The standard deviation of the resource utilization over time.
d. The maximum number of units of resource utilized at any one time.
e. The current number of units of resource utilized.

In our case example, the results show that on the average 23.4185 of the 60 units of Device 10H1 were utilized and that 40 units of Device 10H1 were busy at any one time over the simulation period. This implies that there be more than enough units of Device 10H1 assigned to the CDP 602A. However, when courses 602D, 015C, 016C, 017C, and 018C are eventually converted into self-paced courses requiring Device 10H1 service, a better utilization of Device 10H1 is expected.

Table 6. Device 10H1 Utilization Statistics

**RESOURCE STATISTICS**

| RESOURCE NUMBER | RESOURCE LABEL | CURRENT CAPACITY | AVERAGE UTILIZATION | STANDARD DEVIATION | MAXIMUM UTILIZATION | CURRENT UTILIZATION |
|---|---|---|---|---|---|---|
| 1 | 10H1 | 60 | 23.4185 | 4.1378 | 40 | 25 |

## V. POTENTIAL USES OF THE MODEL

This section discusses some potential future uses the student flow simulation model has after it is developed and evaluated.

## Earlier Planning Possible

CNEWS planners use of a student flow model should increase their training effectiveness by allowing them to consider and test a variety of course combinations before a course or curriculum configuration is chosen for final development and implementation. The use of a student flow model should allow course planning to take place earlier and provide a means for more effective planning dialog among individual course developers, course operations personnel, and CNEWS planners. The model will allow course and curriculum planning to include a larger number of curriculum design options to be considered. It may be possible to adapt future versions of the model to CNEWS management information system (MIS) efforts, and selected cost features could be developed for the model that could reflect the Navy's training resource acquisition and management policies and directives at the CNEWS operational level.

A significant potential advantage of the student flow simulation model for CNEWS planners is in the development and implementation of the individualized EW operator curriculum and the introduction of the multi-stationed, generalized EW operator trainer, Device 10H1. This will include the ability to examine quickly the likely impact on the curriculum of adopting new training technology and methods for courses of instruction being planned to meet new training requirements as they arise.

The selection of data to use as inputs to the development of the EW student flow model was made with these types of future capabilities in mind. The model will allow: (1) the interactive examination of the essential elements of curriculum planning in terms of a range of choices, (2) the identification of the advantages and/or disadvantages of such choices as they are likely to affect student flow and facility/resource operations, and (3) planning checks for internal scheduling conflicts as curriculum choices are made.

## Likely Impacts of Planned Alternatives

The model should be of value to EW school curriculum planners in considering the impact of alternatives to meet changes in training requirements by providing insights into the likely impacts of such alternatives prior to having to make large and often long-term investments in time and resources. Such insights might include, for example, "optimizing" the change over from lockstep to individualized portions of the curriculum. The "optimization" might take place in terms of altering course convening frequencies to minimize competition for available resources, or the identification of potential course conflicts so that alternatives could be considered such as course restructuring or the use of double shift operations for a limited time.

Since the EW school will be shifting from lockstep courses to individualized course in the EW operator curriculum in a phased program over several years, the student flow model should provide insights into the likely impact of such an incremental program and the likely operational problems to be encountered when students exist from a lockstep course and enter an individualized course, or vice versa. This condition will occur during the next few years since the maintenance courses will remain lockstep for the near future and the operator training courses will be incrementally converted to individualized courses. The model will provide insights into the probable impacts of such changes and will provide forecasts of the likely effects of establishing and operating dual pipelines for a period of time during such a changeover.

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## ABOUT THE AUTHORS


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# THE ROLE OF THE PRIME AIRFRAME MANUFACTURER AS AN INSTRUCTIONAL SYSTEMS DEVELOPER

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## ABSTRACT

Instructional Systems Development (ISD) in the military has traditionally either been performed in-house or by an independent contractor. Historically, prime airframe manufacturers have neither had the interest nor the technical capabilities to provide this service. Based strictly upon the technical requirements for conducting ISD for an emerging weapon system, however, the airframe manufacturer is in a unique position to concurrently design and develop training in parallel with the aircraft. He has ready access to the technical data, engineering specification and design inputs much earlier than any outside agency. His ability to collect performance data and determine system configuration can expedite the development of training devices specifications thus insuring that devices are delivered in time to begin initial aircrew training. Additionally, training requirements can be considered early enough to be integrated into the design process and actually impact the final system configuration. With the emergence of a "total systems approach" mandated by OMB Circular A109 and DOD 5000.1 and .2, this ISD capability is being developed by the airframe industry and should be considered as an integral part of the prime's responsibility during Full Scale Development.

## INTRODUCTION

Traditionally, the role of the airframe manufacturer in instructional systems development has been limited to support of the process through providing technical data and documentation on the system configuration and performance. As part of contractual obligation during Full-Scale Engineering Development (FSED), he is typically required to develop a human factors task analysis for system operators and logistic support analysis for maintenance functions. In addition, he is required to develop Type 1 training and identify training equipment needed to support Operational Testing and Evaluation (OT&E) for the initial cadre of system operators and maintainers. In this role, little of what he does is immediately applicable to the formal Instructional Systems Development (ISD) process required to analyze, design and develop aircrew and maintenance training programs for operational personnel. Recent modifications to the system acquisition process (e.g., OMB A-109 and DOD 5000.1 and .2), which dictate a total systems approach, are realigning these traditional roles and placing the prime contractor in the forefront of the analysis process to insure that training and personnel requirements are appropriately addressed from the outset of system conceptualization. These changes, requiring the prime contractor to be heavily involved in the front-end analysis, provides an opportunity for him to contribute significantly to the design and development of training early in the system acquisition process. In fact, it makes him the logical candidate to perform ISD in parallel with the design and development of the air vehicle.

There are those, of course, who would argue with this conclusion. The view is held by many that the ISD requirement is best satisfied by anyone <u>but</u> the prime airframe manufacturer. This opinion <u>is</u> predominately shared by those whose main product line is training support and services, as well as a few skeptical military customers. The reasons given cite the opinion that most airframe manufacturers do not have sufficient technical expertise nor an adequate background and/or involvement in training technology research and development to remain current. They, also, point out that a prime contractor's main responsibility is the air vehicle and that everything else is secondary; hence, manpower, budgets, and schedules will not receive sufficient management priority in the training areas. In essence they maintain there are too many competing elements to allow training to receive the attention it deserves. This may be true in some instances but this problem is not unique to airframe manufacturers. The lack of a proper management commitment to training is an institutional and organizational problem, not a technical problem, and thus can be solved through enlightened management and program supervision supported by corporate policy. Those who maintain that the prime contractor should not perform ISD, however, will also be the first to admit that ISD <u>cannot</u> be performed without the prime contractor. <u>Hence</u>, we have a classic dilemma as to what his proper role should be?

## INSTRUCTIONAL SYSTEMS DEVELOPMENT BY THE PRIME

The prime normally conducts the initial task analysis as part of the human factors design activities. Rather than being a legitimate task analysis it is typically a task inventory or listing instead of a complete analysis of the tasks and their behaviorial requirements. However, if properly conducted and performed in light of future ISD requirements, this initial task analysis can be expanded to include performance conditions and standards; task frequency, criticality and difficulty; task initiation and termination cues; crew and crew coordination responsibilities; and system/subsystem interfaces. The addition of this analytic data to the task inventory can then be directly applied to subsequent ISD activities and the development of functional specifications for training devices in a more timely and logical manner. In the early stages of system engineering and design, the prime airframe manufacturer is the only one who has access to adequate technical data to perform such a detailed analysis. Thus, he can conduct the initial ISD step (analysis of job performance requirements) much earlier than either independent contractors or the military using command's in-house staff.

More critical than the early ISD analysis step is the ability to expedite the identification and definition of training device requirements so that long lead time items required to develop training equipment can be adjusted to match aircraft delivery schedules. Historically, the ISD process, which strives to optimize training resources, is inhibited or constrained by training equipment which does not adequately address training requirements or is not available in time to be integrated into the training program at Ready for Training (RFT) dates. There are several factors contributing to this situation. (1) The ISD process is not initiated early enough to impact training device design, (2) Training devices are designed by engineers with insufficient data concerning training needs, and (3) Training device manufacturers must rely upon technical data from the airframe contractor which is typically not timely nor sufficiently detailed. All three of these factors can be eliminated or minimized if the airframe manufacturer, as the instructional systems designer and developer, is also responsible for the detailed functional specification of device characteristics and performance. ISD personnel can be integrated directly into the airframe design process where they have access to current technical data and documentation and are able to influence the aircraft design in areas that could effect training and ultimately system effectiveness.

The prime contractor designs and develops Type 1 training as part of his FSED contract. Normally, this training does not follow the systematic and orderly process of ISD and, hence, is not adequate in content or format for formal operational training. If, however, the airframe manufacturer was also responsible for the ISD of aircrew and maintenance training programs, Type 1 training materials and equipment could be designed and developed using standard ISD methodology so that it could be integrated into follow-on training programs. This approach would not only be more effective and efficient in terms of time, resources and costs but it would also provide an opportunity to validate the training during OT&E and make required revisions prior to Initial Operational Capability (IOC) and/or RFT. In addition, actual training equipment required for operational training could be prototyped and tested simultaneously with the aircraft, by the Test Forces during Type 1 training, allowing RFT certification prior to starting operational training. Not only would this procedure insure that the devices met the training requirements but it would also insure that the full suite of devices are in place, providing a totally integrated training system, for formal training which is something that has not been possible to date.

## SUMMARY

The prime manufacturer's extensive involvement in the "front-end" analysis, mandated by the new procurement procedures, will increase his knowledge and understanding of operational requirements needed to design hardware to meet mission needs. His primary concern must be with a total system concept, not just meeting hardware and software specifications. Personnel and training requirements are an integral part of the total system and, hence, must be integrated into the prime contractor design and development process from the outset. Thus, airframe manufacturers must develop the technical capabilities to deal with these expanded areas of responsibility. Given this changing set of conditions for doing business with the military customer and the need to broaden technical expertise to include state-of-the-art training technology, the airframe manufacturer is now in a position to assume the role of an instructional system designer and developer in addition to being the designer and developer of the aircraft. He has immediate access to all the prerequisite technical data and documentation. ISD can be integrated with system engineering and delivery schedules for the air vehicle. His subject matter experts (SME's) will be system engineers and test pilots with detailed knowledge of system components and operations. He has access to SME's from the outset, hence facilitating his ability to complete early analysis of system requirements. These capabilities, combined with the requirements for a total systems approach, logically argues that the system and all its constituent elements should be derived from a common source—the prime contractor. Otherwise, instead of a totally integrated system, the results will continue to be a series of subsystems, each independently optimized for its own unique function resulting in suboptimization. This is clearly not the goal of the more effective and efficient system procurement processes being developed. The time has come for training to become an integral part of the system and for the prime contractor to assume the role and responsibility for ISD just as with any other element of the systems. In an age of shrinking budgets and escalating costs, this is the only solution which makes sense either in terms of system effectiveness or efficiency. The airframe industry is prepared to meet the challenge for total system responsibility and accountability, including all the elements of personnel and training required to support that system.

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# OPTIMIZING SIMULATOR-AIRCRAFT TRAINING MIXES*

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ABSTRACT

Under the assumptions that (1) as simulator training increases, required aircraft training decreases to some non-negative minimum and that (2) at any point, the rate at which required aircraft training decreases is a fixed proportion of the difference between present required training and the minimum required training achievable, the function relating $\underline{x}$, the simulation training received, with $\underline{y}$, the subsequent training required in the actual aircraft to attain criterion, will be of the form $y = ae^{-bx} + c$. This formulation has tremendous utility in allowing the training analyst to calculate the most cost effective mixes of simulator and aircraft training. This approach was applied in the U.S. Army's acceptance tests of the AH-1 flight simulator (AH1FS). Non-linear regression analysis of data collected on some 30 individual maneuvers indicates the methodology is viable. A straightforward methodology for incorporating these results into analysis of the combined cost and training effectiveness of the AH1FS and similar training devices is presented.

Implicit in the acquisition of any simulation training system is the assumption that training objectives are more economically attained through a mix of simulation and hands-on training than through hands-on training alone. This was the concept guiding the U.S. Army when in 1967 the basic requirements and projections for a Synthetic Flight Training System (SFTS) were first elaborated. Faced on the one hand by rapidly increasing training and operating costs and encouraged on the other by advances being made in training simulator technology, the Army embarked on a long-range SFTS development program, developing first the UH-1 Iroquois (Huey) instrument flight simulator and then the CH-47 Chinook visual flight simulator. The latest addition to the SFTS program is the AH-1 Cobra visual flight and weapons system simulator (AH1FS).

This paper reports in detail a novel methodology used in determining the training effectiveness of the AH1FS as a training medium for transitioning rated rotary wing aviators to the AH-1 aircraft. The report is presented in three general sections. The first describes the derivation of the methodology; the second presents the results of applying this methodology in testing the AH1FS; and the third describes how the data obtained is to be used in determining optimal mixes of simulator and aircraft training.

## METHODOLOGY FORMULATION

### Training Effectiveness

As indicated above, the motive driving training simulator development is economy in training. The economy achieved is, of course, determined by the cost and the effectiveness of a unit of simulator training relative to the cost and effectiveness of a unit of (in the present case) aircraft training. With past simulators, the cost differential between simulator and aircraft training has been so great that a marginally effective simulator might be used to realize overall training savings. However, as simulators have grown more complex and expensive to operate, the differential has shrunk to the point that precise quantitative determination of training effectiveness is becoming a major step in U.S. Army simulator testing and acceptance procedures.

Training effectiveness can be viewed and defined in many ways, but as Roscoe (1) points out, traditional measures of effectiveness fail to take into consideration costs associated with pretraining or simulator training. Roscoe has proposed the cumulative transfer effectiveness ratio (CTER) as an alternative with more utility for the training psychologist. The CTER is defined as

$$\text{CTER} = (x_o - y_i) / x_i,$$

where $\underline{x_i}$ is training received in a simulator, $\underline{y_i}$ is training required in the aircraft after $\underline{x_i}$ simulator training, and $\underline{x_o}$ is training that would be required in the aircraft were no simulator available. The ratio compares training savings in the aircraft as a function of amount of simulator training; a CTER of .75 would indicate that for some $\underline{x_i}$ units of simulator training, each unit is equivalent to .75 unit of aircraft training. The CTER has great utility to the training psychologist as a measure of training effectiveness and was quite successfully employed in Holman's (2) evaluation of the CH-47 flight simulator.

But, as Roscoe points out, the CTER is not a constant but is very much a decreasing function of the value of $\underline{x_i}$. In fact, if $\underline{x_o} - \underline{y_i} \geq 0$, it can be seen that

$$\lim_{x_i \to \infty} \left[ \frac{x_o - y_i}{x_i} \right] = 0. \qquad (1)$$

Thus, it is the case that each empirically established CTER will be valid only for some arbitrarily small neighborhood around its particular $\underline{x_i}$.

*The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

From the training psychologist's point of view, an ideal measure of training effectiveness should convey the same information as does the CTER but should also allow computation of training effectiveness for all $x_i$. This could be accomplished by regressing CTER on various experimental values of x, but a simpler and more direct approach is to regress y on x. That is, find a suitable prediction rule or function which can be used to relate the independent variable of x relatively inexpensive units of flight simulator training with the dependent variable of y relatively expensive units of aircraft training required to attain the training objective. Once this training effectiveness function relating units of simulator training with units of subsequently required aircraft training is determined, the training psychologist can apply to the function the respective cost factors associated with the two training media and then minimize the resulting total cost function.

Derivation of Model

Now that the potential utility of such a concept of training effectiveness has been illustrated, how can the function relating x and y be characterized? In this section a model relating simulator and aircraft training will be developed, both intuitively and theoretically, and evaluated against extant empirical data.

At the intuitive level, one would expect the function sought to exhibit several characteristics. At $x = 0$, i.e., no simulator training, y is equal to the CTER's $y_0$, the amount of aircraft training required when a simulator is not used. As x increases, y should decrease; that is, as amount of simulator training increases, amount of subsequent required aircraft training should decrease. However, the rate of decrease should not be constant; from the nature of the CTER, it is known that the pay-back from investing more units of training in the simulator becomes less and less. That is, although the rate of change of y with increasing x is negative, the rate of change approaches zero, resulting in some asymptotic minimum non-negative value of y which will be denoted by c. The value of c represents the amount of aircraft training that must be done to attain the training objective regardless of the amount of simulator training administered. For the training effectiveness model, c is conceptually representative of those "task elements" which are not trained by simulation but must be learned in the aircraft. For those cases in which all task elements are trained in the simulator, c would be equal to zero. An intuitive graph of the function is shown at Figure 1.

Consider y as it ranges between a maximum at $y_0$ and a minimum at $y = c$. The quantity $y_0 - c$ can be considered as representative of the potential aircraft savings that can be realized by using the simulator. Assume that, as x increases, the rate at which y decreases (and savings accrue) is a constant proportion of $y - c$. This can be represented mathematically as the linear differential equation

$$\frac{d(y - c)}{dx} = -b(y - c), \tag{2}$$

where b is the proportional constant. Substituting g for $y - c$, the equation becomes

$$\frac{d(g)}{dx} = -b(g)$$

which has general solution

$$g = ae^{-bx}, \tag{3}$$

where a is an arbitrary constant. Replacing g by $y - c$ yields

$$y - c = ae^{-bx} \tag{4}$$

$$y = ae^{-bx} + c.$$

Equation (4) is then a good theoretical candidate for the function the training psychologist seeks in relating simulator training with aircraft training.

Other than the study reported here, little quantitative data for evaluation of the model are to be found in the literature; most training effectiveness studies, being oriented toward transfer of training proportions or toward CTERs, have not systematically varied x, the amount of simulator training given. A notable exception occurs in a study conducted by Povenmire and Roscoe (3). In evaluating a generic aircraft simulator, Povenmire and Roscoe gave general aviation students up to 11 hours instruction in the simulator followed by training to criterion in the aircraft. Data from their Table 3 are plotted in Figure 2. The curve in Figure 2 is a rough fit of equation 4 to their data. For this fit, the proportional constant b has an approximate magnitude of .397, which is well within its theoretically expected range.

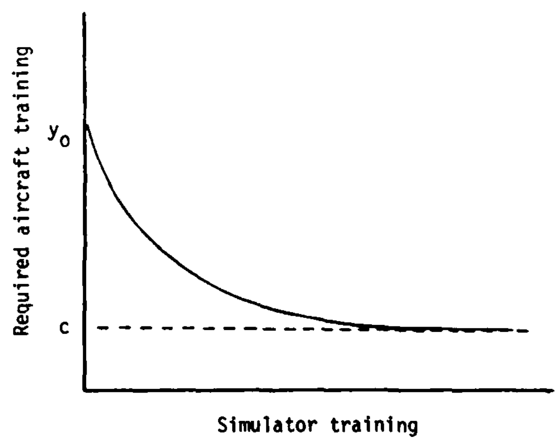



Figure 1. Hypothetical relation between antecedent simulator training and subsequent required aircraft training.

## Level of Analysis

To this point, no mention has been made of the specific level at which the proposed analysis is to be made. In the case of the Povenmire and Roscoe data, the analysis was made at the level of the entire curriculum: data were collected in terms of the total time students were trained in the simulator or in the aircraft. Thus, any measure of effectiveness derived is a measure of the training device as a whole. However, it may be that the device is more effective in one area of training than in another. The training analyst requires information as to the device's areas of greatest effectiveness in order that training curricula may be developed which capitalize on the simulator's training strengths. One way this information may be obtained is by evaluating the simulator at the level of individual training maneuvers. In using this level of approach in the evaluation of the U.S. Army's CH-47 helicopter flight simulator (CH47FS), Holman (2) found that, although the CH47FS is effective overall (.82 average CTER), CTERs for individual maneuvers ranged from zero to 2.80.

In view of this finding, and since the AH1FS has incorporated in it most of the CH47FS's technical design features, it was decided to evaluate the AH1FS at the level of individual maneuvers. The general approach taken was to administer regular flight students varying amounts of AH1FS training in each maneuver and then to observe the additional amounts of aircraft training required for them to attain proficiency.

## PROCEDURE

### Subjects

Instructors. Instructor pilots (IPs) then currently assigned to the Attack/Aeroscout Branch of Hanchey Division of the Department of Flight Training of the Directorate of Training of the U.S. Army Aviation Center (USAAVNC) served as flight instructors. The IPs were all experienced aviators, qualified in the AH-1 aircraft, and graduates of the Attack/Aeroscout Branch's Methods of Instruction course.

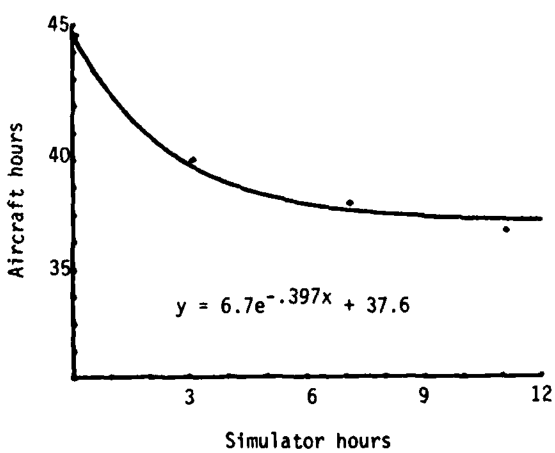



Figure 2. Fit of model to Povenmire & Roscoe results.

Students. Experimental subjects (Ss) were rated Army rotary wing aviators selected from regular USAAVNC AH-1 transition classes in residence during April-August 1979. Some Ss received all their training in the AH-1 aircraft; others received AH1FS training followed by training in the aircraft.

Administrative constraints and scheduled daily AH1FS availability restricted the experimental sample size per class to 8 for aircraft training only and to 6 for simulator plus aircraft training. Only those commissioned officer students in the grade of captain or below and those warrant officer students in the grade CW3 or below were considered. The remaining selection criterion was number of total flight hours: those Ss with the lowest number of total flight hours were selected.

### Apparatus

The AH1FS is a high-technology training device which simulates the AH-1 aircraft cockpit and instrumentation, aircraft motion and vibration, aircraft power plant and weapons noise, and out-the-window view. It is designed to afford training in visual contact flight, instrument flight, and weapons delivery techniques.

### Preliminary Activities

Instructor training. Prior to start of the study proper, 3 experienced IPs, selected by the Scout/Attack Branch, received a 5-day "instructor-operator" course conducted by the simulator manufacturer. Primary topics were simulator operating procedures and simulator-specific instructional strategies. At the end of training, all three were judged as qualified AH1FS instructor-operators by both the manufacturer and the Army simulator test-acceptance pilot assigned to the project.

Data specifications. As indicated above, it was decided the level of analysis for the study would be that of the individual maneuver. Prior to the study's start, the suite of maneuvers then taught by the Scout/Attack Branch was identified. Following the general format developed by Holman (2), a booklet allowing for collecting data on up to four repetitions of each maneuver daily was developed. Table 2 contains a list of the maneuvers evaluated. Data collected on any one maneuver repetition included the number of training minutes spent in performing the repetition and a rating of the trainee's overall performance on the repetition. The scale used for the overall rating is shown in Figure 3.

All Scout/Attack Branch AH-1 IPs were instructed in the use of the data collection booklet and rating scale. Prior to commencement of the test proper, each instructor pilot had satisfactorily demonstrated use of the booklet by recording data from one of his regular transition course students.

AH1FS training amount determination. As indicated previously, the overall test methodology was to involve observing the amount of aircraft training required after various amounts of AH1FS training. Subsequent regression analysis of these data would require that the amounts of AH1FS training selected be independent of the trainees. Specifi-

| Rating | Description |
|---|---|
| 0 | Demonstration by IP; no evaluation. |
| 1 | IP immediately had to take back control of the aircraft. |
| 2 | Performance deteriorated until IP was finally obliged to take back control of aircraft. |
| 3 | Student required considerable verbal assistance. |
| 4 | Some parameters within course limits; verbal correction from IP required. |
| 5 | Some verbal assistance required; less than half of parameters within course limits. |
| 6 | Minimal verbal assistance; more than one-half parameters within course limits. |
| 7 | Few parameters outside course limits; student corrected performance with coaching; still lacks good control touch. |
| 8 | All parameters within course limits; work needed on control touch. |
| 9 | Outstanding; no perceptible deviations from standards; SIP-level performance. |

Figure 3. Maneuver rating scale.

cally, in such a regression analysis, Ss cannot have been trained to some level of proficiency; having done so, in effect, would have allowed each trainee to determine his own amount of AH1FS training and thereby violate the underlying assumption of independent assignment of training amounts. Thus it was determined that for each maneuver, Ss would each receive one of 3 pre-specified numbers of training repetitions in the AH1FS.

Inspection of Figure 1 indicates that the magnitudes of the 3 values chosen can be critical to the analysis. If all 3 independent variable values are chosen too large, then the resulting dependent variable values will all lie in the asymptotic portion of the curve and inferences about the descending portion of the curve may lack precision. On the other hand, if all 3 values are chosen too small, then the dependent variable values will all lie in the descending portion of the curve and inferences about the magnitude of the asymptote may lack precision. It can be seen that, ideally, independent variable values for each maneuver should be chosen such that resultant dependent variable values fall both in the descending and in the asymptotic portions of the curve.

Since the AH1FS was a new piece of equipment with no quantitative training effectiveness history, estimation of each maneuver's ideal amounts of training was, of necessity, based on several outside considerations. First, Scout/ Attack Branch IPs were asked to estimate the average number of maneuver repetitions the average AH-1 transition course student requires to reach institutional proficiency in the aircraft. Also, for maneuvers common to both the AH-1 and CH-47, data collected in the CH-47 flight simulator evaluation (2) were examined. Then based on these data, on their sizable experience as IPs, and on their perceived effectiveness of the AH1FS as a training device, the AH1FS instructor pilots and the simulator project test pilot individually and then collectively estimated for each maneuver three amounts of AH1FS training that should capture both the descending and the asymptotic portions of the generic curve shown in Figure 1.

## Method

Due to various operational considerations, it was decided that Ss trained in the AH1FS would receive at least some training on all maneuvers in the simulator; data for each maneuver for the condition "no AH1FS training" were to be collected from Ss receiving all their training in the AH-1 aircraft. The normal AH-1 transition course as taught at USAAVNC had a maximum lf 12 students and was of 4 week's duration, with a new class starting every 2 weeks. Ss to receive AH1FS training were selected from every other class; Ss to receive aircraft training only were selected from each class as feasible.

AH1FS training. Simulator-trained Ss followed the same general daily training routine as their aircraft-trained counterparts. The standard daily routine allowed for two instructors each to train 3 students for 1.5 hours apiece. Except for utilization of simulator-specific features such as "freeze," "play-back," and demonstration tapes, the AH1FS instructor pilots followed the same standard curriculum that was being used in the aircraft. The only major departure from the standard was in progression through the curriculum: where individual training progression was profi-

TABLE 1. STUDENT GENERAL CHARACTERISTICS

| | Low | Average | High |
|---|---|---|---|
| 1. Age | 21 | 27 | 32 |
| 2. Total RW flight hours | 160 | 594 | 2500 |
| 3. Total RW flight hours in last 6 months | 0 | 95 | 190 |
| 4. Years since graduation from RW flight school | 0 | 2.3 | 9 |

ciency-based in the aircraft, in the AH1FS it was based on completion of the pre-specified numbers of training iterations of each maneuver. For each S for each maneuver, the pre-specified level of training to be received was assigned randomly under the constraint that overall equal numbers of Ss received each of the 3 levels. After completion of AH1FS training, Ss began training in the aircraft.

Aircraft training. The AH1FS-trained S's first exposure to the AH-1 aircraft was a diagnostic checkride administered by a Standardization Instructor Pilot from the USAAVNC Directorate of Evaluation/Standardization. Based on the results of this checkride, the S's AH1FS instructor continued training him to proficiency in the AH-1 aircraft. When his instructor considered him proficient in the aircraft, the student was given an end of course aircraft checkride by another IP and released from training.

Those Ss not receiving training in the AH1FS received normal instruction and training in the aircraft.

## RESULTS

### Subjects

During the conduct of the study, the Scout/Attack Branch experienced unforseen shortages of both personnel and aircraft. The effects upon the study were two-fold: new instructor pilots with no experience with the data collection booklet entered the training system, and students trained in the aircraft many times received aircraft instruction from more than one instructor pilot. As new instructor pilots began carrying students, they were instructed in the use of the data collection booklet and began collecting data on their students. A new instructor pilot's first students' data were discarded. Also, any student receiving instruction from more than two instructor pilots (not counting the checkride IPs) during the four-week transition course was discarded from the analysis.

Students. A total of 22 Ss began training in the AH1FS. With the exception of one who was grounded for medical reasons unrelated to the test, all successfully completed AH-1 flight training. A total of 25 Ss entered the study to receive aircraft training only. Due to the above-mentioned problems with instructor availability, data from all but 14 of these Ss were discarded. Descriptive data of these 35 Ss is shown in Table 1.

### Maneuvers

Missing data. If in simulator training a S received as many as 2 fewer or as many as 2 more training repetitions for a maneuver than had been assigned him, his data for that maneuver were discarded. This condition generally arose due to abnormally low simulator availability or through oversight on the part of the simulator IPs. Also, for some maneuvers, some Ss trained in the aircraft alone were neither trained to criterion (as defined below) nor tested on that maneuver on the end-of-course checkride. Data in these cases were also discarded. Thus, in most of the results given below, data for a maneuver are based on a sample of less than 35.

Over-training. It was discovered early in the study that, although the AH-1 transition course was (within the limits of its 4-week duration) self-paced and proficiency based, over-training unavoidably occurred on some maneuvers. For example, since most training involving takeoffs and landings or autorotations involved flying a traffic pattern around the training stagefield, students in the aircraft routinely received considerable over-training in flying traffic patterns. Thus, after consulting with all the instructors involved, it was decided that a student would, for purposes of the study, be considered to have attained proficiency on a maneuver in the aircraft when for 3 consecutive training repetitions he had been rated at least a "7" (see Fig. 3) and, of course, provided he was rated at least a "7" on the maneuver on the end-of-course checkride. All aircraft training subsequent to the three "7s" criterion was considered over-training and not included in the analysis below.

Presence of trend. As a general indicant of degree of overall relationship between amount of AH1FS training and subsequent required AH-1 aircraft training, eta-squared was computed for the data for each maneuver. The values found, which can for this sample of Ss be interpreted as the proportion of variance accounted for by knowledge of amount of AH1FS training, are entered in Table 2.

Regression analysis. For each maneuver, the data described above were fit to the function $f(x) = ae^{-bx} + c$ using the SPSS sub-program NON-LINEAR (4). Marquardt's method was used to obtain

TABLE 2. MANEUVER RESULTS

| Maneuver | N | $\eta^2$ | a | b | c | df | F-ratio | Residual |
|---|---|---|---|---|---|---|---|---|
| | | | Parameter Estimates | | | | | |
| Cockpit procedures | 34 | .82 | 6.41 | 1.878 | 2.65 | 1,30 | 3.711 | 1.39 |
| Takeoff to hover | 32 | .56 | 10.24 | 3979 | 3.68 | 1,28 | .074 | 4.00 |
| Hover flight | 33 | .59 | 11.87 | .368 | 3.35 | 1,29 | .033 | 4.87 |
| Hover landing | 35 | .71 | 10.23 | .390 | 2.98 | 1,31 | .029 | 3.14 |
| Hi-speed flight | 33 | .60 | 6.89 | 1.129 | 3.03 | 1,29 | .317 | 2.71 |
| Normal takeoff | 33 | .35 | 13.86 | .161 | 2.57 | 1,29 | .198 | 4.53 |
| Normal approach | 33 | .79 | 9.96 | .131 | 2.02 | 1,29 | .696 | 2.06 |
| Maximum power takeoff | 29 | .63 | 4.56 | .400 | 1.16 | 1,25 | .061 | 1.59 |
| Steep approach | 30 | .44 | 2.88 | .724 | 1.58 | 1,26 | 1.243 | 1.60 |
| Running landing | 23 | .64 | 1.95 | .436 | .78 | 1,19 | 1.180 | .64 |
| Traffic pattern | 33 | .64 | 16.36 | .608 | 4.57 | 1,29 | .024 | 6.05 |
| Hydraulics failure | 27 | .72 | 8.18 | .179 | 1.54 | 1,23 | .036 | 2.84 |
| Forced landing, power recovery | 27 | .53 | 8.35 | $1.5\times10^{6}$ | 3.15 | 1,23 | .038 | 3.92 |
| Autorotation to touchdown | 31 | .53 | 8.34 | $5.1\times10^{35}$ | 4.44 | 1,27 | .099 | 3.85 |
| Autorotation with turn | 33 | .29 | 4.57 | .395 | 3.37 | 1,29 | .477 | 3.47 |
| Autorotation, power termination | 19 | .05 | .50 | ·17.20 | 2.00 | 1,15 | .509 | 1.08 |
| Hovering autorotation | 32 | .49 | 3.59 | $1.7\times10^{54}$ | 2.06 | 1,28 | 1.991 | 1.95 |
| Left anti-torque failure | 28 | .61 | 8.52 | .316 | 1.55 | 1,24 | .418 | 3.38 |
| Right anti-torque failure | 27 | .53 | 6.99 | .548 | 1.51 | 1,23 | 1.561 | 2.90 |
| Low level autorotation | 28 | .43 | 3.57 | $2.5\times10^{5}$ | 3.20 | 1,24 | .928 | 2.16 |
| Low level high speed autorotation | 26 | .24 | 1.62 | 1743 | 2.54 | 1,22 | 1.330 | 1.60 |
| Hover out of ground effect | 25 | .56 | 1.90 | $2.2\times10^{5}$ | 1.25 | 1,21 | 3.654 | 1.04 |
| Terrain flight takeoff | 23 | .48 | 3.73 | 1.388 | .27 | 1,19 | .046 | 1.67 |
| Terrain flight | 26 | .44 | 3.81 | 1.149 | .55 | 1,22 | .214 | 1.96 |
| Terrain flight approach | 22 | .36 | 3.29 | 17.16 | 1.00 | 1,18 | .229 | 2.39 |
| SCAS off operations | 22 | .09 | .10 | 1.555 | 2.16 | 1,18 | 1.980 | 1.06 |
| Weapons cockpit procedures | 25 | .49 | 4.54 | 478.7 | .38 | 1,21 | .651 | 2.61 |
| 2.75" FFAR ballistic correction | 27 | .46 | 5.16 | $5.2\times10^{13}$ | .07 | 1,23 | .020 | 2.77 |
| FFAR firing | 28 | .49 | 5.32 | $4.2\times10^{43}$ | .07 | 1,24 | .012 | 2.69 |
| 20mm ballistic correction | 27 | .74 | 2.16 | 3180 | .07 | 1,23 | .147 | .65 |
| 20mm firing | 24 | .65 | 2.38 | $1.6\times10^{7}$ | .08 | 1,20 | .102 | .86 |

parameter estimates; iteration ceased when the largest relative change among the 3 parameters became less than $1.5\times10^{-8}$.

Best fit parameters for each maneuver are entered in Table 2. Also shown for each is its RMS residual and an F-ratio of goodness-of-fit (5). In the interest of conserving space, graphic results for only 4 maneuvers are shown; these appear in Figures 4-7 and are discussed in more detail below.

## DISCUSSION

As indicated at the outset, one of the major objectives of the test of the AH1FS was to evaluate a methodology for quantifying training and cost effectiveness of simulators. In this section, the success of the methodology in capturing the simulator's effectiveness will be scrutinized, and then a straightforward application of the results to curriculum development will be outlined.

### Training Effectiveness

The overall data indicate that the AH1FS is an effective device in training nearly all maneuvers investigated. This is evidenced by the general reduction in required aircraft training for each maneuver following simulator training (i.e., for all maneuvers, the rate parameter $\underline{b}$ indicates a decreasing function of $\underline{x}$). But the specific results of particular interest are those pertaining to the accuracy of the transfer model and the success of the methodology in obtaining usable input for efficient curriculum design.

Presence of trends. The initial analysis of the data indicates there is indeed, in most cases, a functional relationship to be found between

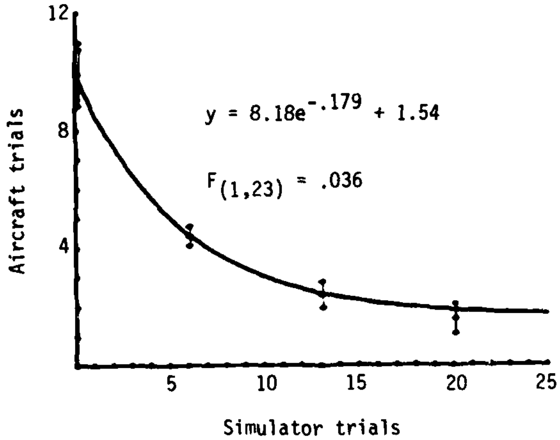



Figure 4. Hydraulics failure.

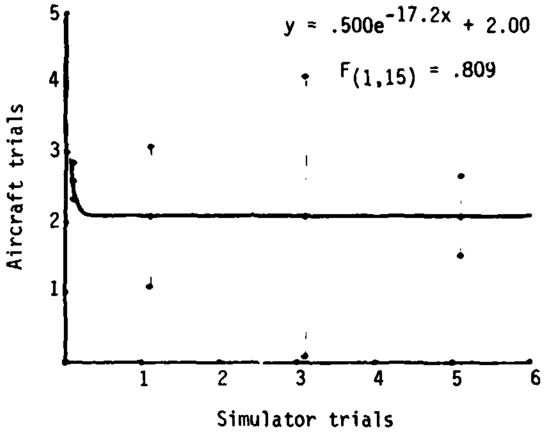



Figure 5. Autorotation, termination with power.

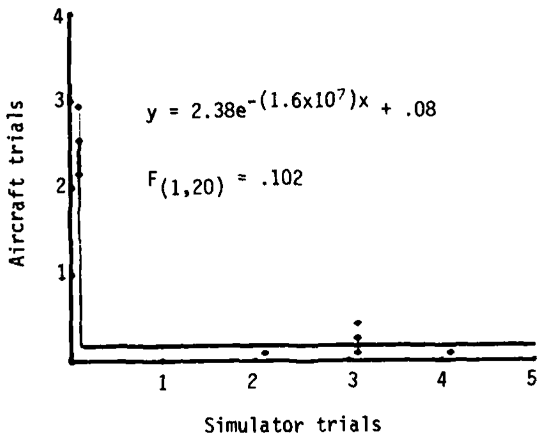



Figure 6. 20mm firing.

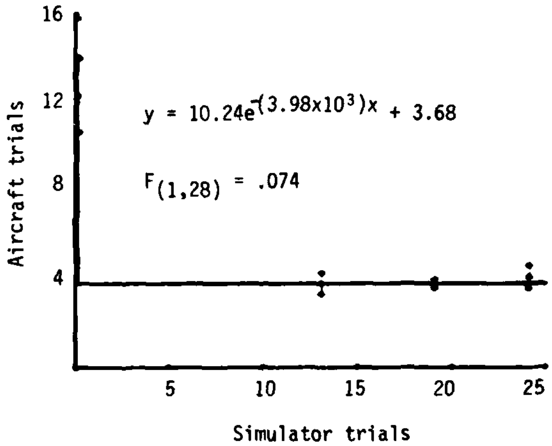



Figure 7. Takeoff to a hover.

amount of simulator training and amount of subsequent aircraft training. Table 2 shows that for this sample, except for "autorotation, termination with power" and "SCAS off operations," between 25 and 80 percent of the variance in aircraft training amounts can be accounted for by amount of simulator training, depending on the maneuver. Hence, there is some motivation for attempting to fit a model to the data.

Goodness-of-fit. In all cases, the model fits the data for each maneuver with values for $a$ and $c$ within their theoretically expected ranges. (Problems with values for $b$ will be discussed below.) However, it is difficult to judge the absolute goodness of fit of any model. For the curve-fitting routine used with most, parameter values are selected that maximize the precision with which the dependent variable can be predicted from the independent variable. Of course, the predicted values and their corresponding observed dependent variable values will differ; the magnitude of the variance of this difference is a general indicant of goodness of fit: small variance results from a good fit. However, it is also the case that for a given level of the independent variable, there will be variance in the resultant levels of dependent variable observed. If this variance is conceptualized as the "noise" inherent in the data, then at least that much "noise" is also to be expected in the precision of prediction using the best fit parameters. To the extent the variance of the fit's precision exceeds that of the dependent variable observed values, the fit can be regarded as bad. Conversely, a good fit will yield a precision variance not significantly larger than the dependent variable variance. The F-ratios in Table 2 compare these variances; none is significant at the $\alpha$ = .05 level. But this is somewhat to be expected: the experimental design could economically allow sampling at only 4 values of the independent value, and the model is left to fit the 4 resulting mean dependent variable values with 3 free parameters. It should be pointed out that a "good" fit is not necessarily "the" fit; there are other models and theoretical functions that would fit the data just as well or even better. For example, Cronholm (6) has pointed out that, if both simulator and aircraft learning curves are assumed exponential with rate parameters $g$ and $h$, respectively, then a very good case can be made for a function of the form

$$y = (h^{-1}) \ln (ae^{-gx} + c).$$

Thus it may only be concluded that there is no cogent reason for rejecting as a viable heuristic the model under consideration.

Individual maneuvers. The maneuver "best fit" curves obtained can be arbitrarily placed in four categories represented by Figures 4-7.

The first category, of which Figure 4, "hydraulics failure," is an example, consists of those "well-behaved" curves for which $a$ is large relative to $c$ and the rate parameter $b$ is not too precipitous. As inspection of Table 2 parameter values shows, this was the case with the majority of the maneuvers evaluated.

A second category, represented by Figure 5, "autorotation, termination with power," consists of those maneuvers for which $a$ is small relative to $c$. This relationship is indicative of poor transfer to the aircraft and occurred with only one other task, "SCAS-off operations."

A third category, represented by Figure 6, "20mm firing," is characterized by values of $c$ close to zero. A negligible value of $c$ can, as previously discussed, be considered indicative that complete transfer from simulator to aircraft was attained. The five gunnery tasks and "terrain flight take-off" fall into this category.

The last category is represented by Figure 7, "take-off to a hover." As mentioned previously, ideally, experimental values of the independent variable should be chosen such that not all three yield dependent variable values falling in the asymptotic portion of the curve. Despite the attempts made to avoid them, such choices were evidently made in the cases of "take-off to a hover," "forced landing with power recovery," "touch-down autorotation," "hovering autorotation," "low level autorotation," "low level high speed autorotation," and "hover out of ground effect."

Consider Figure 7. Based on various considerations, it was decided to sample the independent variable at levels of 0, 13, 19, and 24 repetitions. Inspection of Figure 7's best fit curve indicates that 13 or more AH1FS training repetitions yield results in the asymptotic area of the function. The reiterative curve-fitting routine used, in effect, fit these asymptotic data with a line parallel to the abscissa.* Although it may be that one training repetition in the AH1FS is efficacious to the extent indicated by the curve, it is very much more likely that, had an independent variable value in the range of 3-7 repetitions been chosen, a much less acute function would have been obtained.

Integration of Cost with Training Effectiveness

Since costing procedures for both the simulator and the aircraft are carried out in terms of hours of operation rather than in numbers of maneuver repetitions, prior to integrating cost and training effectiveness, the training analyst should determine the average time required per maneuver in each training device. Then the appropriate transformations of axes of curves such as those in Figures 4 through 7 can be made such that the abscissae's unit of measure is units of simulator time and the ordinates' unit of measure is units of aircraft time.

Device operation costs. To determine economically optimal mixes of simulator and aircraft time, the training analyst must be provided the cost per unit of operating time for both devices. If this figure for the simulator is designated $C_S$, then the function describing the total cost of $x$ units of simulator training time will be the product $C_S x$, as shown in Figure 8a. Likewise, if after $x$ units of simulator training, $y$ units of aircraft training are required, the total cost of this training will be the product $C_A y$, where $C_A$ is the cost per unit of aircraft training time. Since it has been shown that the $y$ units of required aircraft training time can be expressed as a function of $x$ as $ae^{-bx} + c$, then the cost of required aircraft training can be more explicitly expressed as $C_A(ae^{-bx} + c)$ as in Figure 8b. Then, for any one maneuver, the total cost can be expressed as

$$C = C_S x + C_A(ae^{-bx} + c), \tag{5}$$

which is illustrated graphically in Figure 8c.

Inspection of Figure 8c indicates it has a point at which total cost is minimized, and it can be shown mathematically** that equation 5 is at a minimum when

$$x = (\ln C_A + \ln a + \ln B - \ln C_S)\ (b^{-1}) \tag{6}$$

If for any maneuver $m$ this optimal value of $x$ is denoted as $x'_m$, then total optimized training cost for all $M$ maneuvers can be expressed as

$$C'_T = \sum_{m=1}^{M} \left[ C_S x'_m + C_A\ (a_m e^{-b_m x'_m} + c_m) \right] \tag{7}$$

* Note that for moderately large values of $b$, the value of $ae^{-bx}$ very quickly approaches zero.

** $\frac{dC}{dx} = C_S - C_A abe^{-bx}$, which, when set at zero and solved for $x$, yields equation 6.

$\frac{d^2C}{dx^2} > 0$ (given $a > 0$ and $b > 0$) implies $x$ in equation 6 represents a minimum.

and the raw savings realized will be, of course, the difference between $C_T$ evaluated at $x = 0$ and the $C_T^*$ of equation 7.

Thus it can be seen that the model and methodology presented here are both viable and of great utility to the training analyst.

## Further Considerations

Although the methodology presented here is fairly straightforward, there are some additional factors to be kept in mind in the details of applying its results in development of a simulator-based training system.

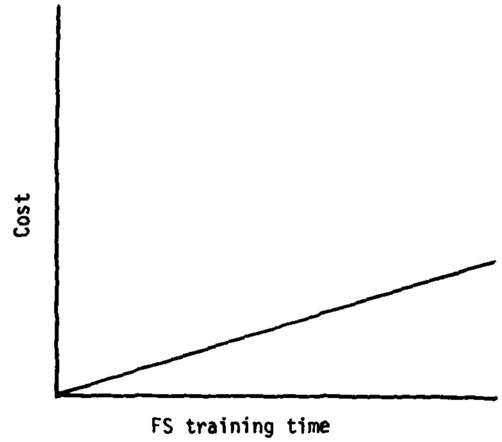
Effects of curriculum. It is an inescapable fact that, regardless of the level of technology and the sophistication of a simulator, its effectiveness is a function of how it is used, of how the trainer incorporates its features into a training program. The quantitative measures of effectiveness determined by this study are very much a function of how the IPs used the simulator as a training device. As the simulator instructional tactics are refined, the AH1FS's effectiveness should improve. Considered in this light, the trade-off curves determined by the study represent not the optimum effectiveness of the device, but the baseline effectiveness.

Restricted device availability. As mentioned in the introduction, most modern simulators are high cost assets and must be distributed over a large number of trainees. In all cases, the training analyst will have the device available for some finite period each day. In many cases the analyst is also faced with cycling through the curriculum a large number of students within a fixed number of training days. These restrictions determine the amount of simulator time that will be available to each student. Ideally, the amount of time allocable per student would be at least equal to the total optimal maneuver training times. In many instances, this is not the case and less than optimal training curricula must be set up according to some trade-off scheme.

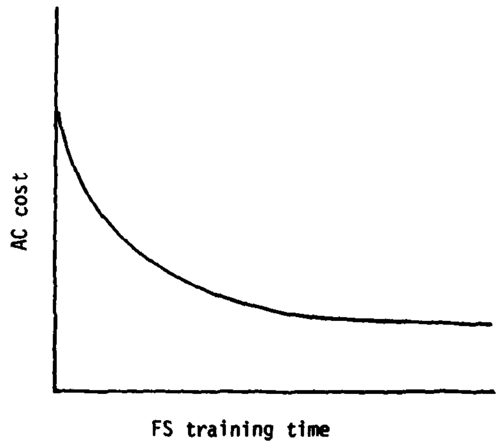
In his implementation of the integration procedures outlined here, Hopkins (7) ordered the simulator trainable maneuvers in terms of each maneuver's savings per hour of simulator operation. (In general, more savings per unit of simulator operating time accrue to those maneuvers for which the difference $a - c$ is great and the rate parameter $b$ is large.) Choosing a hypothetical 3.5 hour availability per student, he simply cumulated the $x^*$ values (in terms of time) down the rank-ordered list of maneuvers until they totalled 3.5 hours. Other trade-off schemes might alternatively involve such considerations as weighting each maneuver according to the danger associated with performing it in the aircraft.

## Conclusions

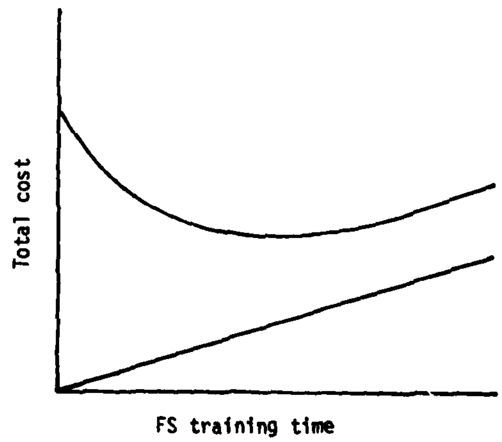
At the practical level, the model and methodology have been demonstrated as both viable and of utility. The model does not concern itself directly with such issues as fidelity and realism, but addresses directly the effectiveness of the simulator in decreasing required aircraft training time. Aircraft training time is expressed as a




a. Cumulative FS training cost as a function of FS training time.




b. Cumulative aircraft training cost as a function of FS training time.




c. Cumulative total cost as a function of FS training time.

Figure 8. Integration of simulator and aircraft training costs.

sum of two factors; the model can be easily expanded to include other factors such as student experience or aptitude or cumulative negative effects of simulator training. For mathematical rigor, the number of levels of the independent variable sampled should be at least one more than the number of free parameters estimated. With careful selection of levels of the independent variable, there is no requirement that some Ss be used for "control" data and receive no simulator training.

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# TRANSFER OF TRAINING EFFECTIVENESS EVALUATION FOR U.S. NAVY DEVICE 2B35

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## ABSTRACT

Training effectiveness of Navy Device 2B35, a computer image visual system used in Navy Advanced Jet Phase UPT, was evaluated utilizing a transfer of training design. Comparisons were made for two simulator groups and a control group for the Familiarization, Night Familiarization, and Carrier Qualification stages of training; for the Weapons stage training, comparisons were made for a single simulator group and a control group. Results are presented separately for the various training stages. Implications for Navy UPT, the Navy VTXTS procurement, instructor training, and for visual simulation in general are drawn.

## I. INTRODUCTION

The U.S. Navy was the first of the military services to exploit visual flight simulation for Undergraduate Pilot Training (UPT). In 1972, a prototype wide-angle computer-image visual display system was installed on a 2F90 operational flight trainer (OFT) for the TA-4J Advanced Jet phase training aircraft. Following an extensive evaluation (1) of its potential for enhancing that phase of Navy UPT, decision was made to procure two additional devices. This allowed one such visual trainer at each of the Navy's three Advanced Jet training sites. The two production devices, slightly modified versions of the original prototype, were designated Device 2B35 and were put into operational use in 1976.

Coincident with their installation, the Advanced Jet syllabus was revised (2) to provide approximately six hours in the visual trainer during the Familiarization Stage (FAM), eight hours of device training at the start of the Weapons Stage (WEP), and a brief session for practice of carrier deck emergency procedures prior to Carrier Qualification (CQ). It is interesting to note that any students who do not receive the prescribed FAM stage device flights, due to device down-time or other factors, are given two extra aircraft rides. However, students missing the WEP stage device training are not provided any added air time.

Device 2B35 and its antecedent prototype are Computer Image Generation (CIG) visual systems representative of early CIG visual technology. The visual system presents a 60° X 210° field of view by means of three rear-projection screens, each of which is illuminated by a light-valve projector. The scene is full color. The instructor-operator console is relatively unsophisticated, having the visual trainer controls and repeater instruments, a three-monitor TV display of the visual scene, and a teletype printout of selected performance parameters, such as bomb distance data, carrier wire engagement, and the like.

The 2B35 visual system is integrated with a Device 2F90 cockpit. The 2F90 OFT was introduced in the late 1960s. It has a limited pitch, roll, and heave motion system and is used in teaching instrument flight procedures. Because the CIG visual system and the 2F90 device to which it has been attached are inseparable when used in training, further references in this paper to the 2B35 will include both the visual system and the host 2F90 OFT.

As they gained operational experience with the 2B35, the Navy personnel became increasingly concerned about the real training worth of the device. While the training personnel were generally convinced that there was positive training value from the 2B35 for WEP training, they were equally convinced that there were serious undesirable effects from device use during FAM training. The possibility of negative transfer in FAM was of particular concern, because the three sessions in the device were being used to replace two aircraft FAM flights.

Concurrently, there was growing interest DoD-wide in formal evaluation of the training effectiveness of all aircrew training devices, and of flight simulators in particular. This position was endorsed by the Chief of Naval Operations (CNO). It was in response to CNO direction, and in recognition of the user concerns over Device 2B35's training effectiveness, that the Chief of Naval Education and Training (CNET) decided to undertake a rigorous appraisal of the training worth of the 2B35 by means of a transfer of training study. The Navy subsequently contracted with Seville Research Corporation to conduct such a study.

The Transfer of Training Effectiveness Evaluation ($T^2E^2$) study was to be conducted as a joint Navy-contractor effort. Seville would be responsible for the study design, preparation of implementing instructions and material, data analyses, and reporting of results. The Navy retained responsibility for the actual administration of all instruction and data collection, although Seville was to maintain close surveillance over these Navy activities. Navy guidelines for the conduct of the study were that Seville develop an evaluation design which would assure a fair appraisal of the 2B35's training worth, but it was also required that the evaluation would be minimally disruptive of ongoing training activities.

This paper reports the results of the consequent $T^2E^2$ study. It summarizes the necessary preparatory activities, briefly describes the study design, reports the principal effects of device training, and evaluates the probable utility of the 2B35 within the Navy's Advanced Jet pipeline. It also makes certain observations regarding the use of visual flight simulation in future Navy Jet Undergraduate Pilot Training.

## II. METHOD

The study began with a review of the content and management of Navy jet training and an assessment of the 2B35's potential for training. These activities were accomplished through review of Chief of Naval Air Training (CNATRA) syllabi and training materials, interactions with the CNATRA staff, and on-site observations of Advanced Jet training operations at Training Wing 3, NAS Chase Field, Texas, the site selected by the Navy for the study.

### Device 2B35 Training Potential

It quickly became apparent that there were fundamental problems with the 2B35 that would have to be solved before the transfer study could begin. Observation of students and instructors flying the 2B35 convinced the study team that it was neither providing proper cues nor eliciting the correct responses. The two most serious problems, close-in ball and power control and carrier-deck trapping, were believed due to errors in basic modeling which made successful performance of these tasks nearly impossible. User suspicions of negative transfer on tasks involving these device characteristics appeared justified. Fortunately, a priority corrective action program initiated by CNATRA and engineers/programmers from the Naval Training Equipment Center provided assurance that these and other discrepancies could and would be corrected prior to the start of $T^2E^2$ data collection.

Having assurance that the 2B35 could be made to perform properly, it was then necessary to identify the training stages for which suitable image-generating data bases were available. The data bases for ongoing FAM and WEP training were of obvious potential use. In addition, although they were not being used in training, data bases for Night Familiarization (NF) and Field Carrier Landing Practice/Carrier Qualification (FCLP/CQ) were judged to be of potential use. There were, thus, four training stages, FAM, NF, WEP, and FCLP/CQ, which could be examined during the study without extensive new data base development.

### Evaluation Design

The first evaluation design consideration was the selection of a basic training strategy that could be effected within ongoing Navy UPT. The second was the technical concerns underlying development of an experimental design as such.

Training Strategies. Two training strategies were entertained. One would utilize an individual, train-to-proficiency training regimen, while the other would involve a lock-step, constant-time training strategy. The first approach had the advantage of providing information about time or trials required for training and would allow direct computation of both transfer ratios (TRs) and transfer effectiveness ratios (TERs). Unfortunately, this approach could not be implemented without making major changes to the Navy training syllabus and established scheduling procedures, changes that the Navy could not support. Since the fixed-time training regimen was also the training regimen in being, it was selected for the $T^2E^2$. The disadvantages of this regimen from the research viewpoint were more than offset by its operational suitability.

Experimental Design. The experimental design was basically a three group, repeated measures design for the FAM, NF, and FCLP/CQ stages. It provided for three levels of the simulator time variable at each of these stages. At the WEP stage, however, because of limitations on sample size, the design called for only two major groups, a simulator group and a nonsimulator control group.

Training Treatments. The 2B35 training treatments were administered in the following manner. Each student scheduled to begin the FAM Stage, was randomly assigned to one of three FAM treatment groups: Group A, which received four 2-hour sessions in the 2B35 followed by five flights in the TA-4J; Group B, which received two 2-hour 2B35 sessions prior to its five training flights in the TA-4J; and Group C, the control group, which flew seven flights in the TA-4J and received no 2B35 training. This assignment procedure continued until each group had twenty subjects.

As the three FAM groups approached WEP training, half of each group was randomly assigned to a WEP A simulator group, while the other half was assigned to a WEP C nonsimulator control group. This allowed examination of FAM-WEP interaction effects. The WEP A group received four 2-hour 2B35 training sessions, while the WEP C group, of course, received none. Each group (N=30) then received seven WEP training flights in the aircraft.

For FCLP/CQ training, the original A, B, and C groups were reformed, with the A group receiving three 1-hour 2B35 sessions and the B group one such session. The C group, of course received no 2B35 training other than the brief carrier deck emergency procedures training session received by all students during CQ training.

### Performance Measurement

The existing Navy UPT grading system evaluates student pilot performance on a four-point scale: Unsatisfactory=1; Below Average=2; Average=3; and Above Average=4. This grading system was quickly discounted as useful for study purposes due to its lack of discrimination sensitivity. For example, more than 90% of the maneuver grades given were "average." Such "normative" grades may be adequate for local management of students' daily progress, but they were judged not sufficiently sensitive to be of use in training program/treatment effects evaluations.

As a consequence, a performance measurement system involving instructor recordings of observed student control over specified maneuver-critical aircraft parameters such as heading, altitude, time, and airspeed was developed for $T^2E^2$ use. Since this measurement approach has been found by many investigators to provide reliable and discriminating data in flight training studies, it was deemed appropriate for this effort.

Separate performance recording booklets were developed for FAM, NF, and WEP. As will be explained shortly, FCLP/CQ performance was measured differently. For the FAM, NF, and WEP maneuvers, the instructor was required to observe and record at selected times/places within a maneuver whether the student was within prescribed tolerances for specific parameters. Some parameters were measured only once during a maneuver, while others were sampled two or more times. Figure 1 illustrates the procedure. In the example shown, the instructor noted Takeoff rotation airspeed to be 5-10 knots high, attitude as proper, and rate as being over-controlled.

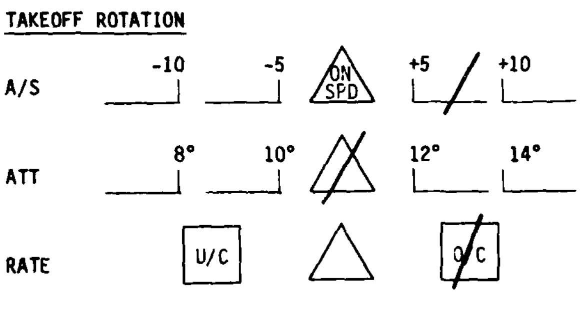


Figure 1. Sample Segment of a FAM Performance Recording Booklet.

Performance recordings were converted to error scores by considering all marks within the center triangles or squares "correct." Any other marks, left or right, counted as errors. By summing errors across all items in the maneuver, a maneuver total error score was obtained; by summing across parameters measured repeatedly, a parameter-control error score was derived. These maneuver and parameter scores were the primary data analyzed for the FAM and NF stages.

There was an additional source of data for the WEP stage. While the recording booklet was used to provide error scores for WEP pattern flying from the abeam position to the release point during 30° dive-angle practice bombing, clock angle and miss-distance scores were also obtained for six practice bomb drops on each training flight--device and aircraft. These bomb drop data thus provided a second data source.

The booklet recording procedure was not suitable for FCLP/CQ performance measurement, since an instructor is not on board the aircraft. The student is, however, under the radio control and guidance of the Landing Signal Officer (LSO) on all FCLP/CQ flights. Further, the LSO routinely observes each student's pattern and landing--in particular from final turn to touchdown--and records descriptive information about each pass using a standardized error notational shorthand. A procedure was developed whereby these data were routinely transcribed to Navy Landing Trend Analysis forms and subsequently converted to error scores for each student landing on each flight. Error scores thus derived were the error data employed for FCLP/CQ analysis. In addition, the LSO's subjective grades were also available for each of the 14 FCLP/CQ Flights, and these were analyzed separately.

## Subjects

Students enter the Advanced Jet Phase of UPT in relatively small weekly or bi-weekly increments of from four to six per "class." Thus, to achieve the desired N of at least 20 subjects per FAM treatment group, it was necessary to use in the $T^2E^2$ all students who entered this training phase at Chase Field from June through September 1978. In all, a total of 64 students were involved. Of these, 59 were subsequently graduated as Naval Aviators.

## Implementation

A number of special implementing procedures were required. Foremost among these were daily lesson guides which controlled the sequence and content of device instruction and defined the procedures to be followed during data collection. Second in importance were the instructor/manager training sessions conducted to assure standardized device training and recording booklet use. Last, but not least, was the close surveillance maintained by the research team over all $T^2E^2$ activities throughout the protracted training/data collection period which extended from June 1978 into March 1979.

# III. RESULTS

The $T^2E^2$ study had three general objectives: (1) to determine whether Device 2B35 visual training produced demonstrable learning; (2) to discover whether such learning as was found transferred to the TA-4J aircraft; and (3) to identify those syllabus stages wherein 2B35 training would be of greatest utility assuming that meaningful transfer were obtained.

## Learning in the 2B35

The FAM and WEP stages were the ones in which the device-trained group (Group A) received four consecutive 2-hour training sessions, thus allowing the clearest examination of across-trial learning. Using group percent error scores for each maneuver flown, learning curves were plotted for the four FAM maneuvers and for the WEP pattern data and bomb scores. All five curves reflected a substantial reduction in group percent error scores from the first to last trial. To illustrate, Figure 2 presents the Group A learning curves for the FAM Stage Full Flap Landing and the WEP pattern over the four simulator sessions.

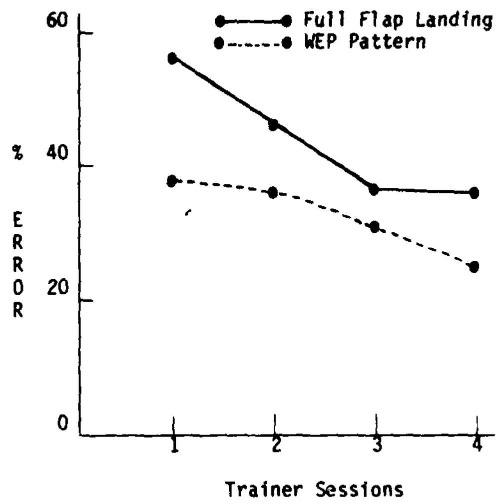


Figure 2. Percent Error on FAM Full Flap Landing and WEP Pattern by Simulator Session (Group A)

From these curves, it is apparent that learning did occur in the 2B35. The reduction in errors by the A Group was statistically significant for all of the FAM maneuvers but the Barrel Roll. For the WEP training, even though the reduction in errors from the first to the fourth simulator sessions was not statistically significant, the trend for that maneuver was also for reduction in errors. Also, that the WEP Pattern data did not asymptote, as was typical of the FAM curves, suggests that further WEP device training could be productive.

Since NF and FCLP/CQ device training was limited to two sessions for the A Group and only one session for the B Group, presentation of learning curves for NF is not useful. However, it should be noted that the NF A Group did show a statistically significant reduction in percent error score over the two device sessions for the Full Flap Landing, further evidence of learning in the 2B35.

During FCLP/CQ device training, both day and night Chase Field FCLP scenes were used for Groups A and B, but the carrier scene was used only during the A Group's training. As a consequence, device learning in this stage could be examined only by comparing Group A's night landing performance during their first and second 2B35 sessions. This analysis showed no significant difference over trials for the error scores derived from the Landing Trend Analysis forms. There was, however, significant improvement in LSO subjective grades over the two sessions, thus providing some indication that FCLP/CQ learning resulted from practice in the 2B35.

In summary, it appears that the types of visual tasks and maneuvers used in the $T^2E^2$ effort can be learned in the 2B35. While there were differences in learning rates and in absolute performance levels achieved across these maneuvers, there remains little doubt that the device can be used to learn visually cued maneuvers. The critical issue is, of course, whether learning in the 2B35 influences subsequent student performance in the TA-4J aircraft.

## Learning in the Aircraft

The objective aircraft data for FAM, NF, WEP, and FCLP/CQ were analyzed as follows. The data from the FAM, NF, and WEP booklets and the derived error scores from the FCLP/CQ Landing Trend Analysis forms were analyzed on the Univac 1100 computer at the Arizona State University Computer Center. The program "Multivariance" was used for the univariate and multivariate analyses of variance, covariance, and regression. Supplementary analyses of these data were also performed on the Univac 1100 using programs from the Statistical Package for the Social Sciences. The .05 probability level was selected as the significance point for all analyses.

The WEP practice bomb score data were examined separately using univariate analyses and correlated t tests. These WEP data were analyzed first as circular error data and then, by trigonometric conversion, as the vertical and horizontal components of the circular error.

The LSO subjectives grades available from the FCLP/CQ flights were also analyzed by either univariate analyses or correlated t tests, as appropriate.

FAM Stage. The fact that the no-device time control group (Group C) received two more aircraft training flights than did Groups A and B allowed for two types of comparisons. Comparison one, the traditional transfer approach, compared the three FAM groups on their first, second, third, fourth, and checkride performances; this omitted the C Group's fifth and sixth training flights. In comparison two, the C Group's first and second flights were ignored, and inter-group comparisons were made between the A and B Groups' first flights against the C Group's third, the A/B second with C's fourth, and so on, up to the checkride. These arrangements are shown in Table 1.

TABLE 1

Device 2B35 versus Control Group Comparison Paradigms (FAM)

| | Group | Flights | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Comparison 1 | A/B | 1 | 2 | 3 | 4 | | | Checkride |
| | C | 1 | 2 | 3 | 4 | (5) | (6) | Checkride |
| Comparison 2 | A/B | | | 1 | 2 | 3 | 4 | Checkride |
| | C | (1) | (2) | 3 | 4 | 5 | 6 | Checkride |

Multivariate analyses (MANOVAs) for both FAM comparison arrangements yielded nonsignificant MVFs for treatments, but the MVFs across flights were significant for all maneuvers except the Straight-In Precautionary Approach (MVF=2.16; df=20.37; $p<.03$). While the nonsimulator C Group tended to make fewer errors than the two simulator groups (A & B), the performance of the control group across the seven aircraft training flights was not significantly different from the performance of the simulator groups which received only five aircraft training flights.

These results show, as would be expected, that all three groups improved with practice. However, the results do not lend any substantial support to a significant simulator-to-aircraft transfer effect, other than the fact that the simulator groups which received two fewer aircraft flights performed in a fashion not significantly different from that of the control group. On the other hand, neither do the results lend support to the converse inference that the all-aircraft training regimen was superior to the simulator-plus-aircraft regimen.

Unfortunately, subject limitations precluded having a fourth group which could have received only five aircraft flights and no 2B35 training. Such a group would have provided more conclusive evidence regarding the degree to which transfer from the 2B35 did or did not account for the A/B Group performance. Without such a group, the possibility remains that the FAM checkride can be "passed" as well with only five TA-4J flights and no device time as it is with seven aircraft rides.

Night FAM Stage. The NF error data from the three treatment groups yielded a significant MVF value favoring Group C (MVF=2.84; df=6, 110; p<.02). In view of the clearly better performance of the nonsimulator Group C, use of the 2B35 for NF training cannot be supported.

FAM Ball-Throttle Control. As indicated earlier, there were significant concerns over the power response and Fresnel Lens Optical Landing System (FLOLS) ball-tracking characteristics of the 2B35. Since substantial software and engineering changes to the 2B35 had been made to support the $T^2E^2$ effort, it was of special interest to determine whether the device might have negative transfer characteristics in these areas. The many power control and ball-tracking measures which had been obtained across the several FAM and NF Full Flap Landing maneuvers flown during the aircraft training flights allowed an examination of both treatment and practice effects of device training on these critical parameters.

Multivariate analysis of the data from the FAM stage showed no significant treatment effects. A similar analysis of the NF data indicated a significant treatment effect in favor of the A simulator group (MVF=3.00; df=12, 104; p<.01). The evidence from these two analyses slightly favors the trainer groups and, at the very least, supports a conclusion that subjects with 2B35 training time clearly were not inferior to their all-aircraft peers with respect to ball control and power control. In view of these outcomes, there is no reason to believe that the 2B35 training given A and B Groups resulted in any negative transfer in these task areas.

WEP Stage Error Data. The MANOVA of the WEP pattern error data yielded a significant treatment effect in favor of the simulator group (MVF=2.63; df=10, 47; p<.02). This was the most clear-cut area of simulator advantage in the study. The data also yielded, as expected, a significant effect across flights, i.e., a learning or practice effect (MVF=2.75; df=20, 37; p<.01).

The analyses of the error scores also showed a significant interaction effect between the two WEP treatments (A or C) and previous FAM/NF treatments (A, B, or C) (MVF=1.65; df=40, 74; p<.03). The pattern of this interaction suggests that, while WEP A treatment positively influenced WEP pattern performance overall, having had the previous 2B35 FAM/NF Group A training was slightly disadvantageous to later WEP flight performance, FAM/NF Group B membership had no clear effect on WEP performance, and FAM/NF Group C membership was slightly advantageous to later WEP performance. One may speculate that students and instructors who had already spent substantial time in the 2B35 (FAM/NF Group A) may have approached further exposure to the device for WEP training less positively than those being introduced to it for the first time.

WEP Stage Practice Bomb Scores. As previously described, practice bomb scores were first analyzed in terms of mean miss distance and then in terms of the mean horizontal and vertical error components of that miss distance. Univariate analyses of these three types of miss distances showed no significant treatment effects, though the A Group's miss distances tended to be somewhat less than those of the control group (Group C). The advantage of 2B35 training to the A Group that was apparent from the WEP objective pattern data analysis did not significantly influence their bombing accuracy, though the trend was for them to be more accurate.

Practice effects as shown by these bomb scores were interesting. While there was substantial improvement in overall miss distance over trials, the horizontal error component improved relatively little. The bulk of the improvement was in the vertical error components. Also, horizontal miss distances were significantly smaller than the vertical miss distances. These data suggest that bomb-run lineup is not a difficult skill, and consequently, there was little room for improvement in horizontal accuracy. On the other hand, the relatively greater vertical error component is related to the pattern elements such as dive angle and release altitude and seems to represent the more difficult aspect of the bombing task.

FCLP/CQ Stage. The objective FCLP/CQ error data were subjected to MANOVA analysis, and the subjective grades were examined by univariate analysis. Multivariate analysis of the LSO-derived error data showed no significant effects due to treatments, i.e., there was no evidence of any differences between simulator and nonsimulator training groups in the aircraft portion of FCLP/CQ. Further, there was no significant change in performance from early FCLP flights to the later flights, i.e., these LSO error data provided no evidence of FCLP/CQ skills learning in the aircraft.

While it is possible that there was no change in student performance over the 13 FCLP flights, i.e., no learning, it is more likely that the LSO error data reflect a shifting frame of reference as to what constitutes an error. This lack of discrimination in the LSO error data was disappointing in view of the usefulness of such data that has been reported by Brictson and Burger (3) in their evaluation of the A-7E Night Carrier Landing Trainer (NCLT).

As has been noted, the LSO subjective grade data were also available for FCLP/CQ flights.

These grades were subjected to univariate analyses of variance which also showed no significant treatment effects. However, all three groups made significant gains from their first three FCLP flights to their last three (A Group: $t$=2.51, $df$=14, $p$<.01; B Group: $t$=5.08, $df$=17, $p$<.01; C Group: $t$=5.20, $df$=19, $p$<.01).

The findings of a clear practice effect reflected by LSO grades is consonant with the preceding statement concerning the likelihood of a shifting scale in the LSO-derived error scores.

There were a number of problems other than measurement that further weakened the FCLP/CQ portion of the study. Among these were schedule conflicts that unavoidably disrupted the orderly flow of 2B35 training, missing data, etc. For these reasons, this evaluation of the 2B35 for use in FCLP/CQ must be viewed as inconclusive.

## IV. DISCUSSION

The central purpose of this study was to conduct an evaluation of the training transfer effects of Device 2B35 for the visually cued tasks required in the Navy's Advanced Jet Undergraduate Pilot Training. The design chosen for the evaluation was necessarily one feasible of implementation within ongoing operational training that would provide the Navy with operationally meaningful transfer information.

The results of this study are generally supportive of visual simulation, though not strongly so, and they are consistent with the findings from similar efforts in which evidence of positive transfer has been obtained, but in which the effects have been modest.

Two recent Air Force UPT studies are of interest in this regard. In the first (4), transfer of basic contact skills from visual simulator training to the T-37 primary jet training aircraft was examined, while the second (5) examined transfer for aerobatic maneuvers. In both studies, evidence of positive transfer was obtained, but the effects were not dramatic. In addition to these two efforts dealing with UPT training, there have been several other research studies addressing the transfer of training potential of visual simulators for basic fighter maneuvers, aerobatics, transition skills, and weapons delivery. For example, one such study (6) conducted in a well-controlled experimental situation, found a consistent trend toward positive training transfer for Navy F-4 pilots on basic fighter maneuvering tasks--but, except for one maneuver, none of the effects was large enough to be statistically significant. Similar results were obtained by the Air Force during their evaluation (7) of the Simulator for Air-to-Air Combat (SAAC); a small positive trend, but not of statistical significance. In contrast, recent studies of the transfer effects of visual simulator training for weapons delivery appear to have the most impressive results. One in particular (8) found substantial positive transfer for air-to-surface weapons delivery.

As can be seen from the several studies cited, the use of visual simulation has produced moderately positive results for transition/familiarization type skills and somewhat stronger positive results for weapons delivery skills. Thus, the results of this $T^2E^2$ can be interpreted as providing modest additional support to the use of visual simulation for such military piloting skills.

In contrast, while the A-7E NCLT study previously cited (3) found a significant transfer effect from that trainer to night carrier qualification, no such effect was found here. Whether the divergence between that study's findings and the present results reflects differences in measurement sensitivity, differences in the way the device was used, or differences between day and night CQ cannot be determined here. However, the NCLT results do suggest FCLP/CQ as an area that might be worthy of further investigation in the UPT setting.

### Findings

Learning in the 2B35. The results show clearly that students learned in the 2B35. While some of the maneuvers showed greater learning than did others, virtually all reflected improvement in task performance as a function of practice. It is apparent also that some of the device training tasks were relatively easy, while others were relatively more difficult. Since there is only one 2B35 device at each Navy Advanced Jet training site, this finding has implications for device use. Tasks easy to learn in the device should not be given much emphasis, particularly if the device time so consumed prevents time being spent on harder to learn tasks.

The most interesting 2B35 learning result, perhaps, is with reference to WEP training. For both the flight pattern skills and for bombing miss distance, it is clear that asymptote had not been reached at the end of four trainer periods. This, in combination with the positive transfer evidence and the fact that there is still room for considerable improvement in the inflight bombing skills, suggests that additional 2B35 WEP training beyond the four periods might be beneficial.

Transfer to the Aircraft. The transfer results provide general support for the continued use of the 2B35 in Navy Advanced Jet training, but its utility in the different stages of that training varies. Specific recommendations concerning the various stages are as follows.

FAM stage. Overall, the transfer data from the present study neither strongly support nor refute the use of the 2B35 for the various FAM stage maneuvers. The all-aircraft control group did not show any significant flight advantage over the device-trained groups, but neither do the data support the contention that the device produced negative transfer with reference to the critical flight skills of ball control and power control. The finding that device-trained students achieve in five aircraft flights a skill level that appears to be the equivalent of that achieved by control students in seven aircraft flights can be construed as supportive of continued use of the 2B35 for FAM instruction, but no clear cut performance advantage was shown for device-trained students. A saving of two aircraft flights is a saving of some consequence, but it is possible that students who received neither the two extra flights nor the 2B35 training might perform equally well. Such a determination, however, would have required a second control group, a requirement beyond study resources.

Based on all these considerations, it is concluded that continued use of the 2B35 for FAM training is warranted.

Night FAM stage. In view of the apparent lack of difficulty with the NF maneuvers, and since the control group showed some flight advantage over the trainer groups, it is concluded that the 2B35 will not provide significant training benefit in the NF stage of Advanced Jet training.

WEP stage. The results of the $T^2E^2$ effort with reference to 2B35 in WEP training provide relatively strong support for continued use of the device in this stage. The acquisition of WEP flight pattern skills in the aircraft is clearly enhanced by 2B35 training. It is of some interest to note, though, that the improvement in WEP aircraft flight pattern skills that results from the 2B35 training is not accompanied by statistically significant differences in bomb scores, though the differences did favor the trainer group.

The data concerning vertical and horizontal error components of bomb scores are of interest in terms of instructional emphasis. This finding, in combination with the fact that asymptotic performance level was not reached in either the trainer or the aircraft, suggests that further 2B35 WEP training might be beneficial, particularly to emphasize the obvious relevance of dive angle and release to the vertical error component.

FCLP/CQ stage. In view of problems experienced in the FCLP/CQ stage of the study and the lack of adequate data, no firm conclusion is drawn relative to the use of the 2B35 to support FCLP/CQ stage training. On an analytical basis, the device would seem to have potential for such use, but on the basis of the empirical results of this study, such use can neither be endorsed nor rejected.

Implications for the Future

This effort adds support to the growing body of literature that shows simulators can provide a positive contribution to the meeting of many visual training requirements, in particular in the areas of contact transition or familiarization training and visual weapons delivery. However, it also indicates that use of visual devices should be based on a careful analysis of the task training requirements, the device's capabilities, and the training system in which it will be employed.

The utility of any given visual device must be viewed in this systems context. For example, because of the Navy's use of the "instruments first, contact later" syllabus sequence in Advanced Jet training, the student has considerable skill in flying the TA-4J aircraft on instruments before he is introduced to the 2B35 visual simulator. This instructional sequence probably limits somewhat the 2B35's potential contribution to the acquisition of FAM aircraft skills. An alternative sequencing or use of a visual device in an earlier phase of training (e.g., the T-2 Basic Jet Phase) might result in a different potential. Future programs, such as the VTXTS, must examine such factors carefully if visual simulation and simulation in general are to contribute both effectiveness and efficiency to undergraduate training.

Though not specifically detailed in this paper, three general requirements for effective future simulator training were highlighted in the $T^2E^2$ effort and are worth noting. These are the requirements for (1) adequate maintenance and personnel support, (2) more objective measures of performance, and (3) instructor training in the instructional use of simulation. With adequate attention to these requirements and to the device and training system factors noted, visual simulation offers significant potential for improving future UPT programs.

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# UNITED AIRLINES USE OF CRI/CMI/CAI

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## ABSTRACT

Since January, 1978, United Airlines has been using the PLATO computerized system to manage an individualized, criterion referenced instructional (CRI) program for newly hired pilots. This program was designed utilizing the CRI concept to take advantage of trainees' existing knowledge repertoires, the different rates at which trainees learn, and for scheduling flexibility. Criterion tests, used to measure expected performance, are presented on the PLATO Computer Managed Instruction (CMI) system; learning resources are printed materials, slide-tapes and video-tapes. The next program that was developed and implemented in January, 1980, Initial First Officer, utilizes both the CMI and Computer Assisted Instruction (CAI) features of PLATO. Also based on CRI design, this program is presented on PLATO as CAI lessons yet still contains the advantages of CMI record keeping. In addition, no external media is necessary, the trainee is provided immediate feedback, and appropriate learning material is given on the spot.

## BACKGROUND

The United Airlines Flight Operations Training Center, located in Denver, Colorado, is a central facility responsible for all training of United's 5,500 pilots. The largest activity is Transition training which qualifies pilots when they move from one airplane to another. In addition, semi-annual Proficiency checks, Recurrent training, Requalification training, Emergency Procedures training, New Hire training, *Initial Captain and Initial First Officer* training is conducted continuously.

## INTRODUCTION TO THE NEW HIRE COURSE

In 1976, the Flight Training Program Development group at United was given the responsibility to develop a training program for newly hired pilots (Second Officers). Specifically it was essential that the training would assure that any newly hired pilot would be able to enter any of the regular transition training programs prepared to meet the objectives of those programs with no modifications to the existing transition training. This meant that new pilots had to be brought up to the entry level of knowledge on which the transition training programs are based. To compound this problem, the expectations of the availability of pilot candidates and the qualification standards for selection led us to expect a wide range of student experience in each class. We could expect students with experience ranging from light airplane time to those with extensive multi-engine jet experience from the military.

It had been eight years since United had hired new pilots, and they had been trained with a conventional, instructor-led classroom course. The factors facing us now, however, pointed out the inefficiency of a traditional, lock-step program which assumes that all trainees require the same training. A program which requires the experienced pilot to sit in a classroom receiving the same lectures as the minimally qualified pilot is not only wasteful and inefficient, but boring as well.

## NEW HIRE COURSE DESIGN

Based on an analysis of the situation, then, it was determined that utilizing the principles of Criterion Referenced Instruction (CRI) would best meet the need. This meant that the program would be results oriented and tailored to meet individual needs. Criterion tests would be used to measure expected performance with mastery of all the tests necessary to complete the course.

The acceptance of CRI principles allows the content of the training to be as much or as little as a particular trainee needs to help master the criterion tests. The number of hours a trainee might spend in training, or the amount of information he or she is exposed to, should have no effect on trainee accountability. The potential impact on trainee time becomes readily apparent.

Use of a CBT System

With CRI as the underlying instructional philosophy for the New Hire Program, the use of a Computer Based Training (CBT) system for administration of the program was considered. After much investigation, United management determined that a CBT system was essential due to the complexity of the training task and the necessity for a very high degree of control over our target population-qualified flight crew members. Errors in record keeping of performance on criterion tests cannot be tolerated in our environment. All parties (Company, Federal Aviation Administration (FAA), Instructors and Flight Crew members) must be assured of complete satisfactory performance on all criterion tests.

The CBT systems available were evaluated and Control Data Corporation's PLATO system was selected because its management system was ideally set up to conduct our application for newly hired pilots. PLATO's Computerized Managed Instruction (CMI) system administers the criterion tests, prescribes training materials and monitors trainee progress. The CMI system is pre-programmed, and as a result, input can be accomplished largely by clerical personnel. In addition, set up of the course and all other necessary input can be handled by development personnel, thus eliminating the need for computer programmers.

## NEW HIRE COURSE DESCRIPTION

United's New Hire Training consists of 28 modules, each of which is further broken down into Objectives or Instructional Units (IUs). Each IU has identified with it one or more Learning Resources (LRs). The content consists of Orientation, Advanced Aeronautical and Job Related subjects.

New Hire Criterion Testing

The criterion testing is accomplished on the Module level but LRs are prescribed on the IU level. For example, if a Module contains 4 IUs, a test is administered for each IU, but mastery/non-mastery scoring takes place on the Module level; that is, a student is tested on a Module basis and cannot choose an individual IU test. The PLATO system keeps track of test mastery and when the Module is completed, indicates to the trainee which, if any, of the IU tests have been mastered. For the unmastered IUs, PLATO prescribes LRs which will help the trainee learn the content in preparation for his/her next attempt at a test. The next time a trainee takes a test, only the unmastered IU tests are presented. In this example, if three of the four IU tests are mastered on the first attempt, the trainee will be tested only on the one unmastered IU on the next attempt. The next test covers the same objective but consists of a different set of questions. If a trainee fails this test, he/she is locked out of further testing, and is either given an alternate LR, or discusses the content with a subject matter expert. Criterion for test mastery varies within Modules, but the range is 80% to 90%.

New Hire Learning Resources

Learning Resources for the Course consist of slide-tapes, video-tapes, emergency equipment and written materials. Most of these were developed specifically for this course, but some of them were chosen from existing materials. Individual study carrels in a Learning Center are available for the individualized instruction.

New Hire Course Options

When going through this course, the trainee has the option of taking the test first or studying the LRs first. Since the trainee receives the course objectives prior to start-up, he/she can determine his/her course of action based on individual knowledge repertoire. For those tests that are mastered first, the trainee is not required to take any LRs, but, of course, is not prohibited from using them. In this manner, training is tailored to individual needs, and training time is not wasted in areas where proficiency is demonstrated.

## RESULTS OF NEW HIRE COURSE

This New Hire Course was conducted from January, 1978 to October, 1979. (The Course has been suspended due to a lack of need for new Second Officers). 835 trainees completed the training in an average time of 9.5 elapsed days with a range from 4 to 15 days. The conventional stand-up course that was replaced by this CRI course took 26 elapsed days. In addition, three instructors who were assigned for subject matter expertise were rarely consulted and were replaced by personnel for coordination at significantly lower salaries.

## Benefits and Advantages

The benefits and advantages of the New Hire Course were significant:

* Reduced training time allowed trainees to move into a transition program earlier, thereby sending well qualified pilots into line operation much sooner.

* Reduced instructor staff eliminated the need to replace the instructor's original positions. All instructors returned to the jobs they had before becoming members of the New Hire staff.

* Instruction is consistent. All trainees receive (if needed) the same instruction and all tests are completed to mastery. This eliminated the conventional, subjective judgments made by instructors. Trainees preferred the new course since they were responsible for identical material and were judged consistently.

* PLATO CMI kept all trainee records current. A trainee knew exactly where he/she was at all times and could plan appropriately. Management was able to see exactly where trainees were at a given moment and could use this data to provide even more individual help if needed.
  Trainees were more relaxed and enjoyed the individual interaction with other trainees that occurs spontaneously with an *individualized program.*

* Changing of poorly worded or unclear questions, misspellings, and all other necessary editing corrections was accomplished on the spot in PLATO. This eliminated the problem of making pencil changes to what would have amounted to multiple hard copies.

* Obviously, money was saved. Exactly how much was not specifically determined due to complex accounting. Trainees became line crew members more quickly than anticipated, and as a result, more flights were flown, more passengers boarded, etc. However, it was conservatively estimated that, after paying for the use of PLATO, well over $100,000 a year would be saved just due to instructor salaries and less trainee time spent in training instead of being productive line pilots.

## Disadvantages

Two major disadvantages existed with the New Hire Course that are worth noting:

* Due to a managerial decision concerning security of the criterion tests, trainees received no feedback to the questions. They did not know which questions were answered correctly or incorrectly. This placed them in more of a straight testing mode rather than in a combination testing/learning process which we consider more desirable. Many students felt this lack of feedback was inappropriate and, at times, caused some minor frustrations.

* We did not use Computer Assisted Instruction (CAI) in this Course. This was due to the lack of programming personnel available who could work with the PLATO language. This dynamic feature, CAI, of a CBT system would have provided trainee - PLATO interaction which would have been more meaningful to the trainee in the learning process.

## FAA Acceptance

The advantages of the New Hire Course, however, strongly outweighed the disadvantages, and the course was widely accepted throughout the company and with the FAA. The FAA regulates all of our courses and approves general content and number of hours required for a given course. Since we could not provide a specific number of hours for New Hire Course completion due to the CRI and individualized concept, FAA approval of the design was a major change in their regulations. This was considered to be a significant breakthrough in the agency's somewhat traditional approach to training, and it paved the way for us to continue in our pursuit of applying the CRI/CMI approach to other courses at the Training Center.

## INTRODUCTION TO IFO

The next course to be redeveloped was the Initial First Officer (IFO) Course which is designed to upgrade Second Officers into First Officers positions. Course content consists of a review of Meteorology, Radar, and United's Flight Operations Manual (FOM), and contains 15 modules broken down into a number of IUs. It is similar to the New Hire Course in that the principles of CRI were used for design and development, and PLATO CMI is used for test administration, LR prescription and record keeping. There are significant differences, however, between the two courses in the areas of criterion, learning resources and feedback.

## IFO COURSE DESCRIPTION

Here's how the IFO Course works:

As in New Hire, the trainee has the option of taking any, or all, of the LRs first, or, if after reading the objectives, of taking the test first. In the IFO Course, however, all of the LRs are CAI lessons instead of the multi-media LRs of the New Hire Course. The use of CAI allowed the Program Development staff to utilize the interaction feature of PLATO to improve instruction. It's also much more efficient for the trainee to have everything right in front of him in one carrel using one piece of equipment. The content of the Course was such that PLATO graphics and a supplemental book of drawings and pictures could easily replace the more expensive use of slide-tapes and video-tapes.

### IFO Criterion Tests

The criterion tests in the IFO Course have two sets of questions, an "A" set and a "B" set. Typically, the trainee will be presented the "A" question first, let's say "1A. If he/she gets it correct, it will be so noted, and he/she will continue on to "2A." If he/she gets it wrong, it will be so noted, and the trainee will receive Feedback (FB) explaining content related to the missed question. After the FB, the next "A" question is presented. This procedure continues until the end of the test. After all of the "A" questions are presented, the trainee receives the "B" questions that directly relate to the missed question(s). If any "B" question is missed, the test is unmastered and the trainee is automatically locked out of further testing in that Module, and must take the appropriate LR(s) before being retested. This cycle continues, then, until mastery is achieved; that is, until no "A" or "B" questions are missed.

## RESULTS OF IFO COURSE

The CRI/IFO Course was conducted from January, 1980 to May, 1980. (Classes have been suspended for a short time due to lack of need for new First Officers). 38 trainees completed the training in an average time of 4.5 elapsed days with the range from 3 to 7 days. The conventional, stand-up course that was replaced by this CRI course took 10 elapsed days. In addition, two instructor positions were eliminated; coordination of the course is provided by the same personnel who administer the New Hire Course.

## COMPARISON OF NEW HIRE AND IFO

Because of the CRI design and the individualization of the IFO Course, the benefits and advantages attained were similar to those accomplished with the New Hire Course. The disadvantages cited in the discussion of New Hire, however, were eliminated in the IFO Course.

### Difference in Feedback

In New Hire, no feedback to the questions was provided; in IFO, not only were the trainees given correct/incorrect answer information, they were also given immediate instruction relating to the subject matter of the question missed. As a result, trainees knew immediately how well they were doing and learned why they answered a question incorrecty. Their learning was then reinforced when they had to answer a similar question to the one missed within a reasonably short period of time. Thus, trainees in the IFO Course were placed in a testing/learning environment as opposed to a strictly testing situation (as in New Hire), and the Course was more meaningful to them. They were also more at ease because they knew how they were progressing with each question and didn't feel the pressure of not knowing how they were doing until the test was completed, as was the case with New Hire.

### Differences in Learning Resources

Another major difference between the two courses was the Learning Resources. While some of the slide-tapes were appropriate for the subject matter in New Hire, many of them were unnecessary, but were done that way simply because that's the way we had done them for many years. Slide-tapes were accepted and were considered the appropriate medium for most learning situations. While designing and developing the IFO Course, we determined that PLATO graphics available through CAI were as appropriate, if not more so, for most of the content than were slide-tapes. Trainees felt that the interaction with PLATO was extremely valuable and meaningful, and they were less bored as a result. Also, editing was handled quickly and efficiently, trainees did not have to cope with potential hardware problems and the lessons were easily accessible and readily available.

## Difference in Criteria

Finally, the criterion established for each course was different. In New Hire, the criterion for module mastery ranged from 80% to 90% while in IFO, the criterion was effectively 100%. In New Hire, when a trainee reached the necessary criterion while taking a test, the test was stopped and the trainee did not see the remaining questions. In IFO, the trainee saw all of the questions and had to answer correctly all of the questions or alternates in order to master a module. In this case, we were assured that the trainees were exposed to all of the needed information, and they attained mastery only after responding correctly to 100% of the questions.

## CONCLUSIONS

Both courses, despite the differences, accomplished their objectives. Trainees who completed training continued on to the next phases with the knowledge necessary to successfully become new Second and First Officers. Further, both courses were objective appraisals of trainee knowledge. Prior to these courses, mere completion of a course was adequate criterion for success. With the new courses, trainees, under more pressure, were somewhat apprehensive at first, but most of them appreciated the logic behind the rationale for objectivity. As with most professionals, when given an opportunity to "prove" themselves, our trainees overcame any misgivings they had, and completed the courses with minimal difficulty.

## FUTURE APPLICATIONS

Due largely to the success of these two courses, United has committed itself to the use of PLATO in the future. Two more applications are underway - the Initial Captain Course and the DC-10 Flight Guidance System are being developed using CRI/CMI/CAI.

In addition, PLATO's largest contribution will be with our new airplane program - the Boeing 767. Not only will PLATO be used in a similar manner as described in this paper, but it will also be used in the simulator as an interface with the simulator computer, and will store all trainee records throughout the entire training program. The 767 program will be on-line in early 1982 and it is anticipated that the program design, development, and implementation, using PLATO as an integral part will be the most modern airplane training program in existence. The use of the CRI/CMI/CAI concept will account for the entire program and should prove to be the most meaningful, successful program ever developed in the airline industry.

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# THE MARINE CORPS MASTERY LEARNING PROJECT: NEW DIRECTIONS IN TRAINING

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## ABSTRACT

The Mastery Learning Project at the Marine Corps Communication-Electronics School in Twentynine Palms, California is the Marine Corps' test bed for the development of a self-paced, mastery-learning strategy. This strategy is viewed as the way to improve personnel and training readiness by providing complex technical instruction in less time, with less academic attrition, and with no degradation in quality. The key to success lies in the emphasis placed on offering closer, more personalized instructor attention to those students who require it. A computer-based management information system provides essential automated support for instructional personnel as well as for all the administrative and managerial functions within the school, thereby permitting substantial reductions in training overhead costs. Experience gained thus far has shown that students are achieving mastery of all learning objectives in 70% of the conventional training time, with academic attrition approaching zero.

Since World War II, the Iwo Jima Memorial, located just outside of Washington, D.C., has been a symbol of Marine Corps valor. But more than that, it has stood as a reminder of our country's readiness to meet and conquer any threat to national security and to those values and principles we cherish. In recent months, however, our readiness has become a matter of grave concern--can we still respond militarily in time of crisis? This leads to the question: What is readiness?

Very simply stated, *readiness* is the synthesization of equipment, people, and training. The most sophisticated equipment in the marketplace, along with the necessary people to operate and maintain it, will not produce readiness without an effective training system. In a certain sense, then, we can say that *readiness equates to training.*

As we enter the 1980s, military training is becoming much more challenging. Specialized skills training, in particular, demands more imaginative responses to constantly changing requirements. The test bed for a long-range Marine Corps program to examine new directions in training which will respond to this challenge is the Computer Based Education (CBE) Project at the Marine Corps Communication-Electronics School in Twentynine Palms, California.

The conventional, lockstep, class-oriented approach to instruction has traditionally been the standard way of conducting training in the Marine Corps. It has served its purpose well, but it is rapidly becoming ineffective in the face of demands being placed upon it by three major factors: technology, manpower, and money. Let us examine each of these.

Technology is changing the world we live in moment by moment. However, the change is insidious. It is happening so fast that it blurs into a gradual continuum and is upon us before we know it. As with our children, growth occurs a little each day and we never notice it... until one evening when we sit down to the dinner table, we find they are no longer there. We are astounded that they have become adults--overnight! How many people still use a wristwatch with a stem winding mechanism? The numbers are rapidly diminishing. And it seems only yesterday that the first electronic calculator fairly dominated the entire surface of a double pedestal desk. Now you can fit one in your wallet. When did this all happen? No question about it, the technology explosion has vastly expanded our operational capabilities, but it has created a dependence at the expense of self-reliance. For some, the deprivation of the automatic garage door opener or the remote TV tuner would be a shattering experience. The pricetag for technology does not end there. The more complex systems--such as those used for military command and control systems--cost dearly and require more highly trained personnel. In short, technology is a double-edged sword. But then, you don't get nuthin' fer nuthin'!

It has been humorously commented that if the safety pin were invented today, it would have two transistors, a regulator, an off-on switch, and would require a service check every six months. This is not meant to poke fun at technology, but merely to underscore the fact that everything is becoming more complex nowadays. How does technology impact on national defense? The U.S. has made the decision not to compete with the Soviet Union in the production of conventional arms. Accordingly, it can only maintain its operational edge--sustain its "essential equivalency"--through the use of technology. This means that greater and greater numbers of multi-purpose, technologically sophisticated weapons systems are entering the military equipment inventory. Just as the cannon was developed to breach forts and later on the tank was invented to breach static defenses, now a whole new generation of military capabilities is being created...which in turn will breed counter capabilities...and so on. These new systems are not merely product improvements on existing systems but are in many cases totally new, add-on systems which further expand the number of equipment end items to operate and maintain. The greater sophistication of these systems makes their operation and maintenance tasks much more complicated and difficult to master and leads to a greater diversification of skills. The generalist is fast giving way to the specialist. In short, greater numbers of more complicated systems require greater numbers of more highly skilled personnel to support them...essentially fewer and fewer "pick and shovel jobs".

One very grave implication of the rapid advances being made by technology is that the individual is given greater control over his environment. Where once the archer could control anything within range of his arrow, and then the pilot had control over anything within range of his aircraft, now the missileman can control those targets within range of his Inter-Continental Ballistic Missile (ICBM). Although this is an impressive operational advancement, it carries with it the serious burden of increased consequences due to human error. What does this mean? Simply that we cannot afford to have poorly or partially trained individuals--each individual must be 100% proficient in his specialty. In summary, technology is generating greater and more complex training requirements.

Manpower is the second factor which is driving the requirement to investigate new directions in training. There are three elements to be considered...Quantity... Quality...and Attitude.

We have been operating without the Draft since 1973, and the validity of the All Volunteer Force is being seriously questioned. Why? Studies have shown that in order to maintain the 2-million plus standing force, approximately 340,000 recruits must be enlisted each year. This equates to about 1300 recruits per working day...a lot of volunteers! Paradoxically, the manpower pool from which these volunteers must be drawn is rapidly declining--there are simply fewer 17-18 year olds than in the past few decades. It has been estimated that by the mid-1980s, one out of every three qualified 18-year-old must be enlisted in order to support the All Volunteer Force. To compound the manpower quantity problem is the fact that retention of mid-career military professionals is becoming more and more difficult...especially among the so called "hard skills" such as electronics maintenance. The lure of higher-paying, less-demanding civilian jobs is hard to combat.

The second element of the manpower issue is quality. Bluntly, fewer and fewer new recruits have the necessary math or verbal skills to successfully complete demanding technical training. Since 1957, the scores registered by high school students on the Scholastic Aptitude Test (SAT) have been plummeting. This lack of qualifications further narrows the manpower pool. It is not that the young people of today are stupid--they are just poorly educated. You can read about it every day in your newspapers and periodicals. One Ohio State University study revealed that approximately 25% of a recent freshman class had to take remedial reading--nearly one-third had to take make-up math! Another study indicates that almost 13% of all 17-year olds are functionally illiterate. This leads to the irrefutable conclusion that the high school diploma is not what it used to be. And again... among the qualified, many are lured away by more profitable careers.

The final aspect of manpower which features into the set of considerations which represent the training challenge is attitude. The Marine Corps seeks individuals who fit the adage: When the going gets tough, the tough get going! However, we are seeing an ever-increasing incidence of an attitudinal problem among our young enlistees which the Commandant of the Marine Corps has very aptly dubbed the "failure stick syndrome." This is reflective of the growing need within our society for instant gratification by the easiest route--a manifestation of the TV-oriented, fast-food mentality. Just like the "hired gun" in the old western movies, who carved a notch in his gun each time he killed someone, many young people today seem to take some sort of perverse pride in the number of notches they can carve in their "failure sticks"--to be success at failure, as it were. The obvious implication this has in our discussion is that technical training and learning do not take place effortlessly, a high degree of mental toughness is required. Consequently, we find more and more cases of students who simply quit because the learning tasks appear to be too difficult and demanding. Mind you, many of these have the necessary cognitive abilities to be successful; their failures can only be attributed to poor attitude and lack of motivation.

The third major factor which contributes to the situation facing the military training establishment is money. In the first place, a shift has taken place since the early Vietnam days in terms of the budget outlays provided to the Department of Defense and the amounts set aside for various human resource programs. Defense spending has fallen from 42% to 23% of the Federal Budget while human resource allocations have climbed from 29% to 53%. The current Iranian crisis has exposed potential weaknesses within the Department of Defense and resulted in calls to raise defense spending. Although the military now enjoys a slightly larger slice of the Gross National Product (GNP), pressure on the Congress to balance the 1981 budget is constant. As a result, any improvements may be short lived. As though proportionate quantitative cuts in the DOD budget were not enough, double digit inflation compounds the matter even further... as it does in every walk of life. Thus, the defense budget is hit from two sides...and within the defense budget, the high acquisition costs of complex weapons systems normally cause a concomitant reduction in dollars available for training.

A major military training center, such as the Marine Corps Communication-Electronics School, is faced with the challenge of providing expanded and more complex training to fewer, less qualified, and less motivated students for less money. M-C-C-E-S or C-and-E School, as it is called in the vernacular, is an expansive facility with the mission of providing training ...electronics fundamentals...operational communications...air control/anti-air warfare operations...and communication-electronics maintenance. Very broadly, C & E School is responsible for training approximately 85% of the personnel who operate or maintain the Marine Corps' command and control communications systems. It conducts 45 courses of instruction leading to 37 Military Occupational Specialities (MOSs)...with several more courses under development. M-C-C-E-S has a yearly input of more than 6000 plus students with a peak load exceeding 2100. The average daily student load is approximately 1700 Marines. C & E is authorized a permanent staff of 51 officers, to becoming better educated in the area of computer based training, to conducting research, and to developing a solid 5-year plan for the acquisition and implementation of our future system. We studied all the significant literature we could get our hands on, we attended seminars and conferences, and we visited most of the major civilian and military institutions involved in similar programs. We also received solicited and unsolicited visits by a number of highly respected experts in the fields of instructional technology and educational psychology. All very willingly lent their professional opinions and confirmed that we were on the right track.

One resounding note which rang loud and clear in all this effort was that any such system as the one we were contemplating had to be based on a marriage of CAI and CMI-with the emphasis on CMI. To avoid possible confusion, which we perceived could arise due to the varying definitions of the terms CAI and CMI which abound, we adopted the umbrella term Computer Based Education (CBE) for future reference to our project. Our 5-year plan laid out our objectives with milestones--as we saw them then-and set forth the essential elements of our CBE system. These consisted of six major subsystems, each containing various application programs. The Training subsystem, of course, reflects the basic requirements for the CAI/ CMI system set forth in our systems specifications; Staff Management addresses the accountability and allocation of our human resources; Resource Allocation does the same thing for our material resources; Instructor Evaluation provides the quality control over our instructors--still the key element in our instructional strategy; Student Management automates the myriad administrative tasks which must occur from the time we learn of a student's assignment to the school to the time he leaves; and Courseware Development is designed to facilitate the monumental task of updating course material. These six subsystems embrace all of the functions which we define as the "educational process" and represent the framework for our CBE system.

There is nothing new about these functions--they all are being performed currently. They are all crucial to our mission. However, our performance of these functions is fast becoming ineffective in an educational environment built on the traditional, lockstep method of instruction. Why? Because the entire approach to training is no longer responsive to the new demands being placed upon it by those external conditions over which we have no control.

Let's take a look at just why lockstep instruction no longer answers the mail. Very simply: it fails to train fully all students and it is fraught with high academic attrition. The major reason for this is that it is based on a Fixed Time/Variable Mastery strategy. A course is conducted over a set time period, and those students who do graduate attain anywhere between 70% and 100% mastery of the learning objectives. Instruction is of necessity geared to the average student. This means that it is too slow for approximately the top one-third of the class and too fast for the bottom one-third. The highly qualified student is capable of mastering all of the learning objectives in much less time than it takes the course to run to completion, whereas the slow student becomes hopelessly lost before he ever gets started. The good students get bored, many never realizing their full potential, some actually becoming "academic" attritions themselves. And the most serious consequence is that we are sending men into the field who may be as low as 70% trained. I doubt if anyone of us would like to be treated by a doctor who was 70% qualified ...or fly with a pilot who was great on take-offs but so-so on landings! What's the answer?

We believe the solution has its foundation in Mastery Learning theory. Pioneered by Dr. Benjamin Bloom of the University of Chicago and further promoted by a number of his disciples, Mastery Learning holds that "all can learn." The implication is that by adapting our instructional approach to the learning capabilities of the student, we can bring all--or nearly all--up to the level of mastery now normally attained by the top 10%. We are confident that this can be achieved. But how will it work?

The educational strategy which supports Mastery Learning is virtually a reversal of that which drives lockstep instruction. Whereas lockstep strategy is based on Fixed Time/ Variable Mastery...Mastery Learning strategy is based on Fixed Mastery/Variable Time (FM/VT). In the FM/VT approach, mastery of all learning objectives is a fixed requirement, the time to master varying according to the unique learning capabilities of each student. When full mastery is attained--measured along the way by successful completion of a series of formative exams and at the end by passing a final, summative exam-the student moves on. The key to control under the FM/VT strategy--and that ingredient which prevents Marines from becoming "career students"--lies in the interactive testing scheme. This disallows a student to exit a question on an exam with the wrong answer. The student is given immediate feedback, and problem areas are identified, signalling the need for instructor intervention. As opposed to the image conjured up by the term "self-paced" instruction, which pictures a student isolated in an antiseptic room, alone with his computer--FM/VT emphasizes the need for the ever-present instructor, and allows him...to employ the one-to-one Socratic method of instruction with those students who need it. Since this age-old, ideal mode of instruction is impossible to employ on a mass scale, FM/VT permits us to implement it "by exception."

On September 1st, 1979, M-C-C-E-S launched into Phase II of the project--the Implementation Phase. With announcement of the system's vendor imminent and delivery of the first increment of the system hardware approximately a year away, we knew we had much work to do to prepare for its arrival. The project team was augmented by additional personnel and restructured into four functional "tracks" under the direct management of the Commanding Officer.

Track 1 was designated the Hardware Track, responsible for making all the preparations necessary to accommodate the equipment when it arrived. It was also tasked to handle all the supply and maintenance requirements for the

463 enlisted personnel, and 48 civilian employees to support this immense training responsibility. However, normal staffing runs at a somewhat reduced level based on the availability of various ranks and MOSs within the Marine Corps.

The impact of Technology, Manpower, and Money on M-C-C-E-S can be driven home by the example of a radar repairman. Fifteen years ago he could fix all of the radars in the Marine Corps inventory with one toolbox...now, radar repair requires a whole array of skills and equipment. Very simply, the increased complexity of technology...and the greater diversity of more sophisticated systems are vastly expanding the range and level of technical skills required by the Marine Corps...with a commensurate increase in the number of personnel who must be trained.

One final aspect of technology which has manpower and money implications and which impacts on the training mission at M-C-C-E-S is the increasing speed of technological change. Scientific advances are hurtling forward in geometric leaps and bounds...to the extent that the effectiveness span of an individual's knowledge, skill, and training is greatly reduced; simply stated, technical training has a built-in decay factor. This requires more frequent updating of training and higher costs. For example, during the decades between 1930 and 1950, tube technology was the existing state of the art. For the most part, a technician who entered the service in 1930 could still operate effectively 20 years later without much, if any, formal retraining. Then in the late 1950s we advanced to minitubes. By the early 1960s we had moved into the world of transistors and medium discrete components...the first attempts at integrated circuits. 1965 found integrated circuits in full bloom...and saw the introduction of layered hybrids...analog techniques being replaced by digital concepts. By 1970 we had reduced multi-integrated circuits to a single chip... and were compressing layers of separate circuitry into multilayer boards by the mid-70s...and this level of technology is now obsolete! Thus, as technological advancements rapidly accelerate on the one hand, and the pool of "first choice" Marines steadily declines on the other hand, C & E School must teach a more complicated array of subjects to lesser quality students. This reduction in quality leads to higher attrition and longer training times, increased in part by the requirement to provide remedial training. The increased pressure to learn greater amounts of more difficult course material also takes its toll in attrition among the qualified but poorly motivated Marines. The higher pay of staff personnel and students leads to higher training overhead costs, especially in the manpower-intensive conventional lockstep method of instruction. Inflation, too, is increasing operating costs at C & E School without an increase in productivity... which, in turn, breeds further inflation. Therefore, the expanded training burden brought about by technological progress, juxtaposed with the depressed manpower situation, creates higher training costs...all at a time when money is becoming more scarce. Our only recourse is to train quicker, better, cheaper.

From the point of view of the trainer, this poses what appears to be an insurmountable problem. We have no control over the march of technology... we have no control over the quantity, quality, and attitude of the manpower we receive...and we have no control over the money we are allocated. What, then, can we possibly do? On the surface it appears that we are faced with an insoluable situation imposed on the training establishment by the factors of Technology, Manpower, and Money. This situation did not develop overnight--as long as ten years ago, the Marine Corps perceived that something had to be done to improve training. It did not view it as a problem, however, but rather as a challenge--and it did something about it--it turned to... AUTOMATION! The reasoning appeared obvious-we needed a better tool. And we got the tool that everyone was starting to get excited about...we acquired a Computer Aided Instruction (CAI) system. It seemed patently clear that the age of television was upon us and that the younger generations related much better to this medium than to the printed word. It stood to reason, then, that students would learn better and faster if they could be taught by television. Therefore, we acquired television-like equipment and started to work.

For six years M-C-C-E-S actively developed CAI lessons, conducted studies and economic analyses, prepared automated data processing (ADP) plans, and so on. We were very busy and enthusiastic. But all we created was a lot of smoke-and no heat. Nothing happened. We failed to produce any tangible results. However, our efforts were not totally in vain. We learned something-we learned what we did not want. Thinking that TV would somehow equate to learning, we had become enamored with the hardware and had leapt right into a hardware solution-without adequately defining the problem. So we restudied our needs and submitted a new set of system requirements to the Commandant of the Marine Corps. And in July of 1976, the Commandant gave the go-ahead to acquire a new system which would be precisely tailored to our needs.

In April of 1977, the CAI Project Team was formally established. It was a pick-up team, comprised solely of in-house personnel--no outside experts were used. As such, it was sort of a sand-lot approach to systems development. But it was effective, in large part because we observed one of the cardinal rules of sound project management--we dedicated this team exclusively to the project under the direction of a full-time Project Officer. The Project Team's first task was to develop a detailed set of system specifications based on the needs assessment that had been submitted to CMC. Two significant aspects of this document were: (1) it was expressed in terms of functional requirements--educational requirements, not hardware preferences; and (2) it included a requirement for Computer Managed Instruction (CMI). Although our mind-set at this time was still primarily oriented to CAI, we had learned enough in the intervening years to know that it was the total management of the educational process--not merely the use of the computer as an instructional medium--which held the greatest promise of economic savings. We were definitely progressing. But we knew that we had much more to learn. So, we devoted 1978 and most of 1979 system. Site preparation and coordination with the system acquisition agency back in Washington, D.C. were its major activities. As an interim measure, necessitated by unexpected-but typical--delays in the system acquisition process, Track 1 undertook negotiations to lease a temporary, low-cost computer system to serve as a training device for our unskilled personnel who would have to function as programmers and system analysts for the CBE system when it was installed. Additionally, it would provide the much needed computer support for development of the various application programs and for our initial endeavors in converting courses to the FM/VT strategy. We were intent on being ready to produce immediate results on any future CBE system as soon as it was installed and operating.

Software-that is, data base design and application program definition, description, and development-was the function assigned to Track 2. This was a most crucial activity if we were to employ the CBE system as more than just an instructional device. The results of this effort would be the ones which would yield our most immediate pay-off in terms of automating mundane, manual tasks in the educational process and reducing the requirement for training support personnel. Coordinating with the various functional sectors of the school, Track 2 succeeded in developing the rudiments of our CBE system. The six major subsystems have been defined and described and their operating algorithms designed--and within each, the top priority applications have been programmed and are operating. One, in particular, has given us our first glimpse of potential personnel savings. Once it is fully implemented, the Automated Order-writing Program will enable MCCES to reduce its Personnel Administration Center staff by four people. A small beginning, but a lot of promise!

Track 3 was charged with the responsibility of developing FM/VT course material. It was toward this effort that M-C-C-E-S received its first outside assistance--augmentation of its staff by a Marine Reserve Colonel, holder of a PhD in Educational Psychology with over 15 years experience. A staunch advocate of FM/VT, he has spearheaded the attack in this endeavor. Although courseware development was ultimately to become a collaborative effort between M-C-C-E-S and outside contractors, the contractual process involved lengthy negotiations. Unable to sit idle while these transactions were completed, the School launched its own program. We were to learn much in this process--indeed, our full perception about the FM/VT approach did not mature until we had actually ventured into the arena ourselves. During this effort, we were also to revise our thinking regarding the role to be played by courseware contractors. We began on a small scale, with plans for progressively expanded courseware conversions.

Our first endeavor actually had its beginnings during the Summer of 1979 with a series of four experiments involving the Fundamentals of Digital Logic Course (FDLC)--a two-week block of instruction at the tail end of our Electronics Fundamentals Course. A small, easily managed instructional package, which all telecommunications and electronics repairmen have to take, it provided the ideal starting point for our FM/VT development. The success of the four experiments, which were conducted rigorously, with control groups taught in lockstep providing the comparison, prompted the school to adopt the FM/VT strategy for this sub-course on a full scale in December 1979. Since the FDLC experiments were first started, a total of 929 students have received instruction under the FM/VT method. 2,878 training days have been saved vis-a-vis the training time which would have been required to train the same number of students under lockstep instruction. This averages out to approximately three training days saved per student. 100% mastery has been achieved in all cases, and there has been zero attrition! The courseware originally developed by M-C-C-E-S has since been smoothed out by a professional courseware firm and is now in active use.

A major disadvantage of the FDLC package which presently exists due to the fact that it is merely a preparatory course, is that once it is completed, students must return to the lockstep environment to pursue their follow-on courses. Tolerating this for the time being in order to gain experience in FM/VT training, M-C-C-E-S proceeded to the next logical step--development of an FM/VT course from which a student could be assigned a Military Occupational Specialty (MOS) and be transferred to the field. It chose to attempt this with the Ground Organizational Radio Repairer Course (GORRC), itself a pilot program in the Marine Corps aimed at redesigning maintenance training to include a level for organizational repair-men-those limited duty repairmen assigned to combat organizations. If conducted in lockstep, this course would have taken approximately 70 training days. However, under the FM/VT strategy the average training time was 49 days--a savings of 21 training days per student. A total of 30 students went through the first class with 100% mastery and no attritions. The total training days saved was 630-just for the first iteration of only one course. Incidently, the graduates of the pilot GORRC have been sufficiently well-received in the field to prompt the Marine Corps to convene a second class in June 1980.

The third phase of our FM/VT development was to apply it to a total training pipeline-that is, to a series of courses leading to a complex technical MOS. We chose for this effort MOS 2841, the full-blown Ground Radio Repairman, a perenially short MOS. Recognizing that the chain of courses--Electronics Fundamentals, Radio Fundamentals, and Ground Radio Repair courses--leading to this MOS contained certain unnecessary and redundant blocks of instruction, our first step was to analyze the requirements and redesign the series into a single, "terminal" course of instruction. The second step was to revise the training material for the FM/VT approach. Comparison of the times required to train a single Ground Radio Repairman reveals that under the current method--the training pipeline approach--it takes 39 weeks. The redesigned, stand-alone course reduces his training time to 20 weeks--if taught under lockstep instruction. But--if taught under FM/VT, it would take approximately 14 weeks-if our past experience in achieving a 30%

reduction in training time is borne out. Translating this into dollar savings, we can expect that the following economies are to be realized for a single student. It costs $6,038.00 to train one student under the current lockstep method--this cost made up of both his salary and his share of the course costs. The redesigned lockstep course would cost approximately $3,100.00. But...if conducted under the FM/VT approach, the costs would dip to roughly $2,170.00. Projecting this time and money savings over a full year, training 480 students as Ground Radio Repairmen, we find that the redesigned lockstep course would reflect a 49% savings in both training dollars and student manyears. The redesigned course under FM/VT would reflect a 64% savings in these costs. The redesigned lockstep course would, indeed, reflect a 49% savings...but it would still result in variable mastery and high attrition. The redesigned FM/VT course, however, would result in even greater savings...and would result in total mastery and no attrition--or close-to zero attrition.

Simple arithmetic tells you that multiplied out over 45 courses of instruction offered by MCCES for the 6,000 plus students per year, the potential savings, in both time, money and manpower is enormous.

The pilot courses for the FM/VT version of the Ground Radio Repairmen now convened on 10 June 1980.

Track 4-last of the implementation tracks--was assigned the responsibility of analyzing the Human Factors requirements which we had learned were so crucial to the success of a computer based training project. To be sure, failure to adequately address these considerations had revealed itself to be the "Achilles Heel" of many other such endeavors. *Paramount among these were: the changing role* of the instructor; the changing role of the student; and "predictive analysis" of student learning potential. We were well aware of the fact that we could expect much apprehension--and possibly resistance--on the part of the instructor regarding CBE. If we did not handle it properly, he could easily begin to feel that he was going to become subordinate to the computer--perhaps even replaced by it. After all, the very nature of lockstep instruction is that it is instructor-centered. Therein, the instructor functions much like an actor on a stage--he learns his lines and he delivers them from a stage to an audience of students. We knew that we had to reassure him that his role was not going to be diminished or eliminated--but rather, that it was going to be expanded and enriched with a great deal more satisfaction than he had known before. He was no longer going to be that actor on the stage, but more the director of the entire production. We have been highly successful in progressively "transforming" our lockstep instructors into FM/VT instructors by involving them, individually and in small groups, totally in the conversion to FM/VT training. We have learned that "involvement" does not merely mean informing them of what is being done or even soliciting their opinions and suggestion--often the furthest extent to which "participative management" is ever pursued. On the contrary, it means having them roll up their sleeves and dig right in under close supervision. It means everything from designing the course material, to actually serving as the instructors in the FM/VT course they have worked on, to finally evaluating the product and revising the courseware based on their evaluations. We are confident that the "heart and mind" of the instructor will not be won by handing him a set of materials developed by outside "experts" with the expectation that he supportively and enthusiastically use it. The "Not Invented Here" syndrome is a fact of life which we must fully recognize.

Hand-in-hand with the changing instructor role is the new and different role of the student. Whereas in the lockstep, instructor-centered mode of instruction he is--to a great extent--an anonymity sitting in the audience, in FM/VT training he becomes the actor in a student-centered production. Each actor has his unique talent--some can dance and some can sing. In the same manner, each student has his unique capabilities--some are better verbally, some have greater mathematical skills, and so on. As it is the job of the director to know the various talents of his actors and to orchestrate them to obtain the very best performance, so it is the job of the FM/VT instructor to know the capabilities of his students and manage them to achieve peak performance.

To assist the instructor in this task, we have attempted to get a better handle on predicting student learning potential. Our first experiment with this took place with the pilot Ground Organizational Radio Repairer Course. Using the Electronic Aptitude (EL) and General Technical Aptitude (GT) scores from the Armed Services Vocational Aptitude Battery (ASVAB) test, we devised a Cognitive Aptitude (C) value for each student, scaled from zero to 3. To this we added a Psychomotor Ability (P) value, based on a very rudimentary, locally-developed psychomotor test. And finally, we ascribed to each student an Affective Traits (A) value derived from scores made on Rotter's Internal-External Locus of Control scale. It was theorized that the A-value would give some indication of a student's probability of perservering through the more complex course material under FM/VT instruction. Realizing that our measurement instruments were very crude at best, we nevertheless used them to develop a Probable Completion Time (PCT) for each student. The results of this initial effort are, of course, inconclusive. Much more extensive work has to be done, and the measurement instruments certainly have to be much further refined. However, we did show that the PCTs for each student were fairly accurate. This has convinced us that we can, in time, become more adept at predicting a student's potential for mastering a set of learning objectives within a certain time frame. Once we can do this with accuracy, we can move one step further toward matching students to programs of instruction that are most within their range of capabilities. In short, we--as directors--can better cast our actors!

In summary, the Marine Corps' CBE system being developed at M-C-C-E-S is a marriage of three basic diciplines: Educational Strategy, Management Theory, and Computer Technology. A review of its salient features reveals that it is...an interactive educational system based on a self-paced, mastery-learning strategy--that is...FM/VT. It emphasizes the importance of the instructor, placing the computer in a subordinate, supportive role which offers... computer data base management that supports the educational strategy.

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# DEVELOPMENT OF TGTS - A TANK GUNNERY TRAINING SIMULATOR

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ABSTRACT

Link-Miles has carried out a Study Programme to develop a Tank Gunnery Training Simulator (TGTS). The Programme was carried out in consultation with many armies worldwide, and in close collaboration with a European army. A survey of Armour training methods and User requirements was made, to define the features which should be provided in the simulator. There followed an Engineering investigation, to establish the design of a cost-effective device which meets the identified training requirements. This paper describes the Study Programme, and the conceptual design of the TGTS.

## BACKGROUND

The Link-Miles Division of The Singer Company has produced a variety of simulators representing tanks, APCs, and other Fighting Vehicles for a number of armies. These were all intended for use in the training of drivers, and are proving to be effective in that rôle. The production of Fighting Vehicle driver training equipment brought the Company into close contact with the Armour training community, and resulted in a growing awareness of its needs. In particular, it was clear that the training of turret crew-members in the skills of gunnery presented problems in view of escalating ammunition costs and the tighter restrictions placed upon the availability of practice ranges. These difficulties are exacerbated by the introduction of higher-cost and longer-range ammunition. In addition, there is the ever present need to achieve and maintain a high level of combat readiness, which requires that crews should frequently exercise their skills.

It appeared to Link-Miles that existing methods and equipment used in turret crew training were not able to support the training which armoured units would require to carry out in the future. The Company therefore resolved to develop new equipment to support tank gunnery training in a cost-effective manner, and initiated a Study Programme to that end.

## THE STUDY PROGRAMME

The Study Programme followed a logical plan, as shown in Figure 1, from an initial survey to determine the requirements of the market to the production of a Proposal for prospective customers.

The Study Programme had three objectives:-

(1) To establish the training which could be achieved in a Tank Gunnery Training Simulator (TGTS), and define the simulator features necessary to facilitate such training.

(2) To investigate the most cost-effective technical methods of providing the required simulator features.

(3) To establish the conceptual design of a simulator which meets the defined requirements.

### Survey of User Requirements

When developing a new product there are two traps into which the unwary may fall. Firstly, they may indulge in "armchair philosophising", and imagine that they already know what the requirements of the potential user will be. Unless the members of the development team are experienced armour crewmen as well as training specialists and engineers, it is very likely that the perceived requirements will be distorted, incomplete, and lay emphasis upon the wrong aspects of training. Secondly, if the needs of one, and only one, army are explored in depth then a solution to them may indeed be reached. However, armies vary considerably in the nature and equipment of their tanks, the quality and number of soldiers to be trained, and the resources at their disposal. Hence any conclusions reached after studying a single army may well be so specific to their needs that extrapolation to other users would not be possible.

For these reasons, the Link-Miles survey was based upon a sample of about ten armies, spread worldwide. They were chosen to reflect different tank types, soldiers (volunteer or conscript), and nature of resources. All the armies approached willingly entered into discussions, and without exception were extremely helpful to the project.

The survey team consisted of staff with expertise in the areas of training psychology, simulation engineering, optics, and related disciplines. A large number of visits were made to training schools, technical establishments, and firing ranges. In-depth discussion with staff at all levels gave an insight into both overall training philosophies and everyday practical problems. Manuals and training aids were made available to the team, who were thus better enabled to understand the intricacies of each army's equipment. An especially close relationship developed with one European army. Members of the Link-Miles team were able, by courtesy of this army, to undergo training in all turret crew functions in a manner similar to that employed for recruits. This training was over an extended period, and included live firing exercises on the range using a variety of ammunition types. This first-hand knowledge and experience of crew functions and the finer points of gunnery technique was invaluable in determining cost-benefit trade-offs and putting into perspective the many ideas and comments received during the survey phase.

The team paid special and detailed attention to all tasks that the turret crew are required to carry out in preparing to fire the tank cannon, searching for and acquiring targets, and engaging them with appropriate gunnery technique. The skills employed at each stage of the operation were identified, and analysed in terms of training requirements. These requirements were then compared with the methods currently in use for training them, and so areas in which synthetic training would be effective were identified.

Thus, from the survey phase there emerged the concept of a simulator which could be used to facilitate gunnery training, and an outline of the attributes which it must have to be successful. This outline, and the accumulated experience of the team, was carried forward to the next phase of the programme.

Performance/Cost Trade-Off Analysis & Specification

Figure 1 shows the way in which the Study Programme was structured. The team commenced work on the programme with no pre-conceived ideas of the training device configuration, nor even any stock techniques which it wished, for commercial reasons, to include in the TGTS. Hence design work proceeded unfettered by any restrictions other than training utility, cost-effectiveness, and good engineering. The final design evolved gradually, with a series of judgements on engineering feasibility, cost of competing techniques, and their impact upon the overall effect of the teaching environment. It was often found that a decision in one area affected other areas of the simulator - areas which had already been tentatively formulated.

In due course, however, an appropriate balance was struck between all factors.

SURVEY OF USER REQUIREMENTS

↓

PERFORMANCE/COST TRADE-OFF ANALYSIS

↓

SPECIFICATION

↓

PROPOSAL

FIGURE 1 - TGTS STUDY PROGRAMME

Scope of Simulator Training

A decision, critical to the remainder of the programme, was made concerning the scope of that training around which the simulator should be configured. A danger here was that any attempt to design a device which would support training of all tank crew-members in the full range of combat duties would inevitably result in a prohibitively expensive piece of equipment. It was also clear that a configuration which permitted training in some aspects of operation would compromise efficiency when teaching other, more essential tasks. It was therefore decided that the simulator was to provide a means for effective training of the turret crew to be skilled in the gunnery task, when using the tank cannon. It should be possible to train recruits in handling all equipment concerned with gunnery, and to work rapidly as a crew when engaging an enemy target. The level of proficiency attained in such a simulator should be at least as great as the level attained with firing on a range. The simulator should also provide practice for trained crews, to maintain their proficiency. It is important to note that the TGTS was deliberately configured to address the problem of basic gunnery training, and not those of battle tactics or co-operation between the turret crew and driver.

Crew to be Trained

Because of the very close interaction between the commander and gunner, it was judged essential that the simulator should include positions for both these crew-members. These positions should permit the teaching of all gunnery activities, including the facility for the commander to aim and fire the gun himself.

The question of whether or not to include the loader in the simulation was more difficult. It appeared that adequate training of loaders could be achieved in other part-task trainers, and that the physical presence of that crew-member in the simulator was not absolutely necessary. An alternative school of thought, however, was that the presence of the loader may be worth the cost increment caused by adding his position in the simulator, complete with an operable breech and loadable rounds. It was therefore determined that the loader would not be included in a basic simulator, but that he would be himself simulated by software and audio generation devices. A loader station, with all training facilities, would however be offered as an optional extra to those customers who wish to train a complete turret crew and are prepared for the additional cost of so doing.

## FEATURES OF THE SIMULATOR

The specification which emerged from the cost-benefit trade-off is summarised in Table 1. It will be seen that there are a few optional items, as discussed above, to cater for the requirements of individual armies which have specific training needs. It is believed, however, that the basic specification reflects a distillation of the requirements of many different armies.

When the simulator features had been broadly defined, the team proceeded to consider the engineering methods by which they may be implemented. Cost-benefit trade-off continued, to ensure that optimum hardware solutions were reached.

An artist's impression of the simulator which emerged from this phase of the programme is shown in Figure 2. The major components of the simulator are discussed below.

TABLE 1 - SIMULATOR FEATURES

| FACILITY | BASIC | OPTION |
|---|---|---|
| Crew to be trained | Commander and Gunner | Loader |
| Types of Shooting | Day (Variable Visibility)<br>Dusk<br>Night | |
| Targets | Up to 4 simultaneously, fixed or moving | |
| Rangefinder | Laser<br>Coincident<br>Stereoscopic<br>Stadiametric | |
| Firing-on-the-move | Visual effects of own tank motion | |
| Observation of fall of shot | Trajectory of tracer<br>Impact effects<br>Ricochet | |
| Trajectory Disturbances | Lateral Wind<br>Ballistic Dispersion<br>Tank Cant | |
| Observation Disturbances | Turret Recoil<br>Gun Flash<br>Gun Smoke | |
| Controls | All controls available to commander and gunner (normal and reversionary) | Loader station controls & breech |
| Terrain and Target Viewing | Commanders Head Up View (direct/through Binoculars)<br>All Commander's Aiming Optics and Forward Vision Block<br>All Gunner's Aiming Optics and Vision Block<br>All Night Vision devices | Loader's Vision Block |
| Commander's Head-Up Field of View | 120° Wide by 30° High. Central 60° Wide sector is targetable | |
| Simulated Range | 800 - 3000 Metres | |
| Sound Effects (examples) | Breech Closing and Loader's Call<br>Turret Rotation<br>Gun Elevation<br>Gun Blast, and Ejection of Shell Case | Background Battle Sounds |
| Communications | Tank Intercom<br>Instructors to Crew<br>Secure Inter-Instructor | Background Radio Chatter |
| Instructor Facilities | View Targetable Terrain Scene<br>Repeat of Commander's and Gunner's view through aiming optics, and Fall of Shot observation<br>Monitor Crew's Principal Controls and Read Outs<br>Hit-Miss Read-Out on VDU and in Hard-Copy<br>Malfunction Introduction capability<br>Introduce trajectory disturbances<br>Pre-programmed Exercises | Record-playback of view through aiming optics |

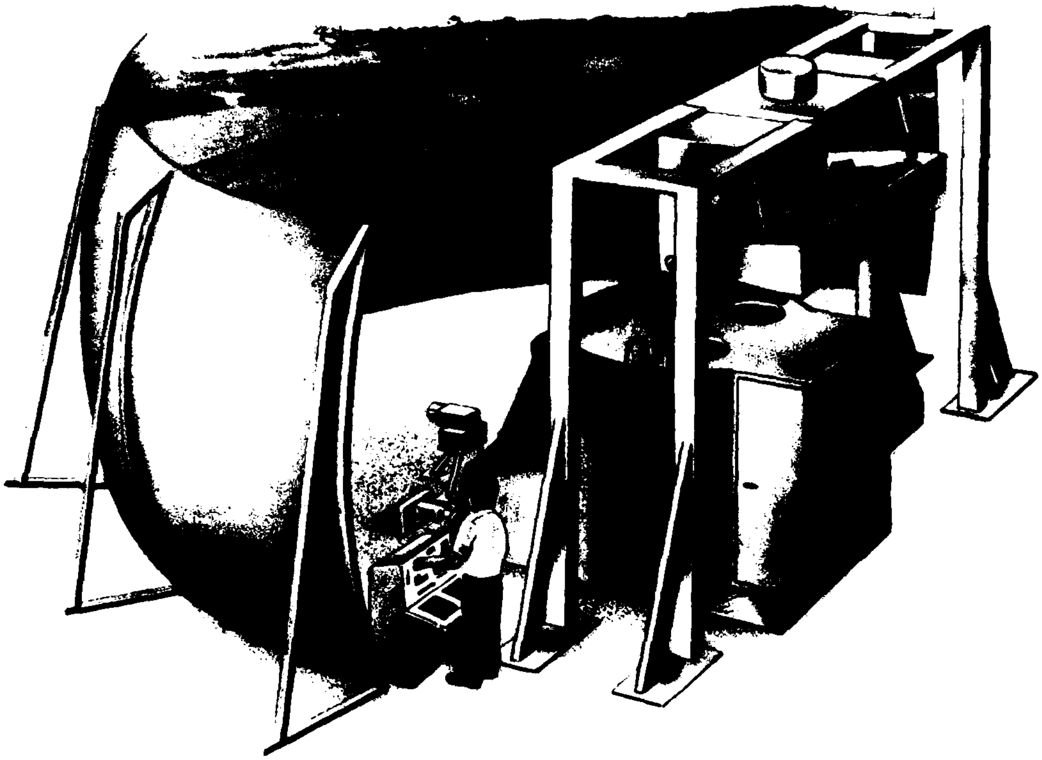

FIGURE 2 - ARTIST'S IMPRESSION OF TGTS

## The Visual System

The most important and demanding aspect of the TGTS is the visual system, by means of which targets, and the terrain in which they are located, are presented to the gunnery crew. Thorough consideration was given to all possible systems, including three-dimensional model boards, computer-generated imagery, photographic film, and television based systems. It is vital to recognise the fact that current technology does not allow the level of visual simulation to reproduce totally the real-world environment. Consequently, it became essential to identify the critical visual system performance requirements necessary to meet the training needs of the TGTS.

It had been established during the survey phase that users need to detect and identify targets in the TGTS at the same range as can be achieved in the actual tank. This enabled the team to determine the minimum resolution of the visual system, so that for example with 7 - power binoculars a 2.3 metre high target may be detected at a range of 3,000 metres and identified by type at 2,000 metres. This requires the targets to be displayed at a high resolution.

To prevent a noticeable difference in quality between targets and terrain - which would effectively make the targets stand out - the terrain image must also be displayed at high resolution. Finally, from the survey and examination of existing training devices, it was clear that both targets and the terrain scene must be realistic. Any simplified presentation, whilst possibly justifiable on the grounds of strict analysis of training requirement, is rapidly dismissed by soldiers as a "shooting gallery", and valuable motivation is soon lost. Also, the presentation of realistic terrain enables training to be given in ground surveillance techniques, and is a valuable additior to the simulator.

In view of all these factors, the system chosen was based upon the projection of large-format high resolution photographic transparencies. Such a system has the following advantages:-

(1) Real-world scene content, allowing both head-up viewing and through all optical devices simultaneously. The resolution obtained is better than 1 arc minute at the unaided eye.

(2) Increased scene content when viewed through

magnifying sights.

(3) Good and realistic colour reproduction.

(4) Very bright images, as powerful projectors may be used.

(5) Effects of restricted visibility (fog, mist) are readily and realistically obtained.

(6) Night scenes can be reproduced, using the appropriate transparencies. By special techniques, the effects of white light or I.R. searchlights can be produced, and thermal or low-light TV viewing systems employed for gunnery.

(7) Realistic target images, matched in quality to the terrain. Targets may be tanks, APCs, trucks, etc. They may be momentarily flashed at a brighter level, under instructor control, to call attention to a particular target for engagement.

(8) Real-world target detection ranges are achieved.

(9) One design of visual system may be used for head-up viewing and all types of sights on any model of tank. There is no need to re-design for each tank.

(10) A single visual system will serve head-up viewing, all vision blocks, and all sights - simultaneously.

(11) Terrain scenarios are readily changed by the instructor.

In the Link-Miles design, three high-powered projectors are used to project the images of large format slides onto a screen which is a segment of a sphere. The images are matrixed to give a field of view 120° wide and 30° high. Rapid auto-change facilities, for 8 slides per projector, are provided to enable different scenes to be presented to trainees as required.

Target images are produced by four smaller projectors, which may be operated independently. The target slides are selectable from magazines, scaled for range, and projected upon the central 60° segment of the screen. The target images are highly realistic, and acceptable to observers. The targets may move under computer control. Programming facilities are included to ensure that moving targets appear to be obscured as they pass behind features on the terrain scene.

All projectors, both terrain and target, are mounted on a large moveable platform supported on a gantry above the simulated turret. This platform is caused to move, for three purposes:-

(1) To give the illusion of turret rotation. The simulated turret remains stationary, and the visual scene rotates relative to it. Although unusual, this arrangement gives a good motion cue without the expense of actually rotating the crew compartment. (Movement of sights in elevation is achieved by actual movement of the sight, as in the real tank).

(2) To give the illusion of whole tank motion when firing on-the-move. When firing on-the-move the most important training task is to use the stabiliser and null out residual motion of the sight graticules.

From the survey, it is believed that there is little training benefit from actually moving the firing point through the simulated terrain. Therefore, in the TGTS, the simulated firing point will remain stationary and the visual effects of motion will be produced, together with signals to drive the stabiliser system. In addition, a small vibrator will be fitted to each crew seat to provide the jolts and disturbances which occur when the tank is moving, and which can affect shooting accuracy.

(3) To give the illusion that the tank is canted, when stationary.

Additional equipment will be used to provide special visual effects when the gun is fired:-

(1) A flash generator will simulate the optical effects of muzzle flash.

(2) Variable filters will give the impression of transitory muzzle smoke.

(3) An eye-safe laser will depict the tracer of the projectile. This will fall according to an accurate trajectory, and will behave with respect to the target according to the accuracy or otherwise of gun lay. For example, it will occult behind the target for an over-shoot, will fall short correctly, or miss the target laterally. The laser will also be used to depict the impact flash of a hit on target.

(4) Burst-effect projectors will be used to produce other visual effects of target hit or miss, such as a pillar of smoke with HESH ammunition.

As a result of (3) and (4), projectile impact effects may be observed, and corrections to aim made using the gunsight graticules.

Range-Finding and Fire Control

As a result of the wide-ranging survey, Link-Miles is aware of the variety of different range-finding and Fire Control systems in use. The precise type fitted to each model of tank simulated will of course be reflected in the TGTS for that tank. Link-Miles has design solutions for all the well-known systems of range-finding:-

(1) Laser

(2) Coincident

(3) Stereoscopic

(4) Stadiametric

The coincident and stereoscopic systems in particular presented difficult design problems, but a simulation technique has been evolved which gives realistic optical effects and a real-world distribution of ranging measurements when used by gunners.

All the facilities of on-board Fire Control Computers are useable in the simulator.

Weapon System Simulation

A key requirement of the weapon system simulation is that it should be extremely accurate, so that hits or misses are a true reflection of gun lay. Anything less would result in a lack of face validity of the TGTS at best, and negative training at worst.

In order to achieve this, it is necessary to compute the relationship of the projectile in flight, the target, and the terrain. The computations take place in a digital computer, which also deals with other system functions. Each terrain scene is digitised, and the information is stored in the computer data base.

When the cannon is fired, the computer continuously solves the ballistic equation of the specific ammunition used, under the simulated conditions (wind, temperature, etc), set by the instructor. The output of this computation is used to position the laser spot, representing the tracer, and to decide the projectile point of impact. Upon impact, the simulation system determines whether or not the target has been hit, and activates appropriate effects on the visual display. The system is able to achieve real-world accuracy, and to calculate miss distance. This information is automatically presented to the instructor, who is thus relieved of the necessity to make subjective decisions based upon his own observations.

The Simulated Turret

Because of the confined space in a real turret, and the restraints placed upon movement and accessibility of equipment, it was considered necessary to achieve a realistic replica of the turret interior. All controls and displays that are relevant to gunnery or communications will be present, and either functional replicas or actual Government Furnished Equipment. Thus the trainees will be enabled to build up fast and accurate movement patterns, which will transfer directly to the controls and viewing devices of the real tank.

The simulated turret will be fabricated from normal engineering materials, and will be much lighter in weight than the armoured turret of the vehicle. It will, however, be strongly built for two reasons:-

(1) During the survey, the Link-Miles team observed that soldiers expect their equipment to be rugged. Simulated tanks are not expected to encounter the hazards of combat, but they are likely to spend many thousands of hours at the mercy of hands and boots!

(2) In the actual tank, the post-firing recoil of the turret is a major cue to successful completion of the firing sequence. In addition, if this cue were omitted from the simulator there would be a danger of poor habits being formed, as the crew would have no incentive to brace against the brow pads prior to firing. For these reasons, the TGTS turret will recoil upon firing, being moved rapidly backwards for a short distance. Cost benefit trade-offs in this area resulted in the recoil cue being limited to 3g.

Aural Simulation

As every Armour crewman knows, tanks are noisy places of work. Some of the sounds heard are irrelevant to training, yet others give useful, sometimes essential, cues to the status of equipment. The TGTS will have an aural simulation system based mainly upon electronic synthesis techniques. The precise sounds to be simulated will depend entirely upon the tank which it is desired to replicate. Some examples are:-

(1) Turret traverse in powered mode

(2) Gun elevation in powered mode

(3) Fume extractor blower

(4) Gun blast and shell case ejection

When a human loader is not present in the simulator, additional systems will produce the sound of the breech closing and the loader's call, on the intercom, that he is ready for firing.

Aural cues will be injected into the crew headsets, which will also be employed for the normal intercom function. Levels will be chosen to equate with those in the tank, with the exception of gun blast. This latter will be set somewhat lower than in the tank, to give good cueing without the health risk of cumulative noise-induced injury. In this context, it is worth recalling that the simulator may well be used to give each crewman many more shots than he could be allowed on a real range. Hence he could be exposed to more noise events in the TGTS.

Aural cueing will, of course, be under instructor control so that a teaching point can be made when required without competing for attention with the simulator itself.

Instructor Facilities

Careful consideration was given to the way in which facilities for the simulator instructor could be arranged. The philosophy adopted was that every effort must be made to ensure the operation and use of TGTS is as simple and self-explanatory as possible. This would minimise the time spent in purely simulator - related operations, and maximise the time which the instructor has to teach and evaluate his trainees.

The TGTS is a little unusual in that there are two instructor stations, although it may be operated by either one or two instructors as desired.

It is recommended that each TGTS should have at least one permanent instructor, who is thoroughly familiar with its operation and is able to employ all the facilities. This will ensure that the potential of the device is fully exploited, and maximum savings of real ammunition are made. This instructor is located at a small look-over console placed immediately beside the simulator, as shown in Figures 2 and 3. The console has complete facilities for the setting up and control of exercises, which may be set up and varied in real time or used in a pre-programmed mode. It is envisaged that the pre-programmed mode will be used primarily, with a large number of exercises stored in the simulation computer. Activation of a particular exercise - chosen from the syllabus of training in a progressive manner - will set up the terrain upon which shooting is to take place. Pre-planned targets will then appear on the terrain in appropriate positions, stationary or moving, at programmed times from exercise start. The instructor will thus be relieved of set-up chores, and some degree of standardised training will be achieved. The instructor will be provided with a variety of monitoring devices, by means of which he may check the actions and progress of his trainees. The most important of these is a visual repeat of the "through the sights" view, with graticule and all visual effects as seen by the turret crew. This enables the instructor to evaluate gun aiming techniques used by the trainees. He does not, however, use this system to decide if the projectile hit or missed the target - that is determined and signalled by the simulator, which gives miss distances plus the corrections required to achieve a hit on target. The information is presented to the instructor on a Visual Display Unit, and is also available in hard copy for debrief purposes. Also for debrief it is possible to use a video tape recorder, which records the "through the sights" view.

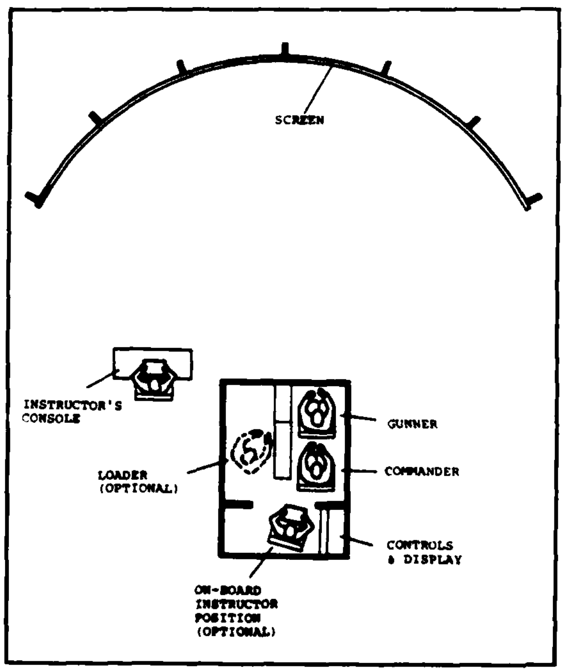


FIGURE 3 - LOCATION OF INSTRUCTORS AND TRAINEES

A second, on-board position for the instructor is provided at the rear of the simulated turret, as shown in Figure 3. This position enables close physical contact with the trainees when necessary, and has very basic controls for activation of exercises plus a "through the sights" repeat display. It is planned that this position should be occupied by the squad instructor assigned to the crew under training, so that he can assist in the early stages of learning to operate the turret equipment. Use of this station will clearly depend upon the philosophy of each particular army. It has therefore been configured as a module, and may be omitted from the TGTS if so required.

## CONCLUSION

It is difficult to adequately summarise the work of several years in a relatively brief paper such as this. Attention has therefore been paid to the more important issues, and has of necessity omitted or glossed over much of the detailed analysis and system design. The final stage of the programme, that of producing a Proposal, has now been reached. Link-Miles is therefore in a position to offer specific Proposals, based on the type of tank operated, to potential customers.

In conclusion, it is worth summarising the most significant features of the TGTS:-

(1) The TGTS enables tank crews to be trained in:-

- (a) Target detection
- (b) Target identification
- (c) Range-finding
- (d) Gun aiming
- (e) Tracking a moving target
- (f) Tracking when own tank is moving
- (g) Gun firing
- (h) Observation of projectile impact effects
- (i) Correction of aim

(2) The design is readily adaptable to different types of tank.

(3) The design is suited to all range-finding and Fire Control Systems, and real-world ranging and shooting accuracies are achieved.

(4) Head-up viewing and use of binoculars is provided for.

(5) All vision devices and sights can be used simultaneously.

(6) Visual system gives a realistic scene with high brightness and resolution. Field of view is $120^{\circ}$ wide.

(7) Up to 4 targets are displayable simultaneously, stationary or moving, with a wide and rapid choice of type.

(8) Comprehensive and realistic sound simulation.

(9) Turret recoil during firing is simulated.

(10) Comprehensive, easy to use instructor's facilities, organised for maximum concentration on the teaching task and standardisation of training. Removal of subjective elements in assessment of shooting accuracy. Either one or two instructors may be employed.

(11) Training of essential elements in firing on-the-move.

(12) All ammunition types can be fired, with appropriate and realistic effects for each one.

(13) Tracer behaves realistically, including occulting behind the target in the event of an overshoot.

(14) Both day and night firing, using all appropriate daylight and special vision devices, with variable visibility.

(15) Simulation is based on digital computation, giving overall accuracy as found in the tank.

(16) Use of the TGTS will enable armies to save costs in the following areas:-

  (a) Reduction in the need to fire live ammunition during training.

  (b) Reduced demand for training ranges.

  (c) Reduced fuel, maintenance, and tank replacement costs due to lower useage.

  (d) Less logistic support required for remote training areas.

(17) The TGTS can be located at the training school or Unit HQ, and is available for use at any time, without limitation due to time of day or week, weather, or availability of consumable stores.

(18) The TGTS is a controllable training environment. Graded exercises may be carried out with close supervision by an instructor who has better information on trainee's actions than he has on a live firing range. It is therefore anticipated that training time will be reduced and standards improved.

ACKNOWLEDGEMENTS

Development of the TGTS was very much a team effort. The author wishes to express thanks to his colleagues at Link-Miles, especially to Des Geere and Eric Gwynn, who were key members of the team throughout the entire programme.

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# 1200 PSI PROPULSION PLANT TRAINER DEVICE 19E22

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## ABSTRACT

The ability of today's surface Navy to carry out its mission depends not only on advanced weapons systems and highly sophisticated electronics countermeasures, but also on the reliability of the steam propulsion plants which generate electrical power and propel the ships around the world. Reliability of a propulsion plant depends upon a crew, both enlisted men and officers, who are well trained in equipment maintenance and the ability to operate the plant safely both under normal and casualty conditions. To achieve this required expertise through training is the function of the 1200 PSI Propulsion Plant Trainer, Device 19E22.

This paper will discuss how the 1200 PSI Propulsion Plant Trainer executes its training mission through the following major elements:

1. A full-scale mockup of the engineering spaces including:

   (a) Engineer Room

   (b) Fire Room and Forced Draft Blower Room

   (c) Auxiliary Machinery Spaces, consisting of Auxiliary Machinery Room No. 1, Auxiliary Machinery Room No. 2, and Electrical Central.

2. A high-speed digital computer and associated Real Time Interface and peripheral equipment.

3. Computer programs including:

   (a) Executive program

   (b) Math Model programs

   (c) Input/Output programs

4. Instructor Station

## BACKGROUND

The days of the World War II stick shift destroyer are long gone. Technological advances and changes in mission requirements during the post World War II period have brought about a new breed of ships to the fleet. Today's surface Navy requires the use of advanced weapons systems and sophisticated electronics to carry out its mission. Larger ships with higher power generation and propulsion capabilities are needed to accomodate and support these complex systems and today's possible tactical situations. The 1200 PSI steam propulsion and power generation plant is one of the high capacity systems in use today on many classes of ships. This plant has a far greater steam generating capability, increased flow rates, and generates steam pressures nearly twice that used on World War II ships. As a result, human responses were no longer adequate to control and regulate these plants and had to give way to sophisticated automated control systems. In turn, this high capacity and complexity of the 1200 PSI plant necessitated the generation of new and improved maintenance and repair techniques, as well as the development of skilled and properly trained personnel to operate and maintain it.

Initially the 1200 PSI plant had poor reliability record, with numerous equipment failures, casualties, personnel injuries and, regretfully, deaths, thus severely affecting the ability of the ships with these plants to perform this mission. A study revealed that much of the problem was due the lack of proper training in plant maintenance and operational procedures. To correct this situation, a 1200 PSI "Hot Plant" was constructed at the Service Schools Command in Great Lakes, Illinois to enhance the training capabilities of the basic machinist mate and boiler technician schools. A second "Hot Plant" was to be constructed at the Surface Warfare Officers School Command in Newport, Rhode Island to support that school's officer and enlisted engineering courses. However, for economic reasons it was decided that the second training plant should be a simulator 1200 PSI Propulsion Plant Trainer. There was considerable opposition to the simulator trainer approach versus a "Hot Plant", but the safety and economic factors, plus manpower savings, were overwhelmingly in favor of the simulator.

## DEVICE 19E22 TRAINING OBJECTIVES

The 1200 PSI Propulsion Plant Trainer student training programs designed to meet the trainer's mission, which is to provide the student with the prerequisite knowledge and skills necessary to competently commence conventional steam propulsion plant qualifications, are structured to meet the following five training objectives:

1. Develop the ability to properly start, operate, and secure the plant under normal conditions.
2. Develop the ability to recognize abnormal conditions and/or symptoms which signal an impending casualty.
3. Develop the ability to take timely and appropriate corrective action which would prevent such an impending casualty from occurring.
4. Develop the ability to timely place the plant in a safe and stabilized condition when a casualty does occur to prevent cascading effects.
5. Develop the ability to restore the plant to normal operating conditions.

Training in the basic skills required to meet these training objectives is provided by the various officer and enlisted personnel service schools. The prime mission of the 1200 PSI trainer is then to provide the necessary "hands-on" training to shape and hone those skills to the required proficiency and concerted operation levels. Specifically, Device 19E22 was to support the following training courses:

1. Department Head Course
   - Hands-on training prior to ship billet
2. 1200 PSI Main Propulsion Assistant (MPA) Course
   - System tracing
   - EOSS operational indoctrination
   - Casualty control procedures
   - Maintenance and inspection
   - Watch standing
   - Automatic boiler control operation
3. 1200 PSI Supervisor's Course
   - Indoctrinate junior officers and SCPO's into 1200 PSI operation and supervision of maintenance

To meet these training requirements, a simulator training device based on the engineering spaces of an FF-1078 class frigate was decided upon by the Navy.

## THE TRAINER AND ITS MISSION

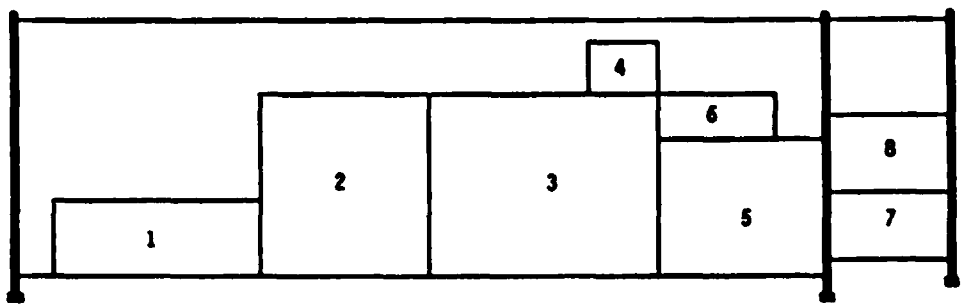
In general the trainer specification required a full scale reproduction of the engineering spaces, and the simulation of all operational equipment which directly support the generation of electrical power and the propulsion of the ship. In addition, the equipment simulation should include visual and aural effects associated with both normal and casualty conditions.

Figure 1 shows the configuration of the trainer in the building as compared to the relative locations of respective engineering spaces aboard the design basis ship. As can be seen, the relative space locations are the same, except that the Auxiliary Machinery Room No. 2 and Electrical Central have been moved in order to accomodate the trainer within a more reasonably sized building. The basic overall trainer dimensions are 133' long, 41' high, and 47' wide. Although direct maintenance access through the simulated bulkheads is provided, they are hidden from direct view and are locked when training is in progress. As a result, the trainees must move about during training exercises in the same manner as they would on board ship.

Operational equipment simulation within the engineering spaces uses a great amount of detail to ensure easy recognition, and to facilitate familiarization with the locations of the various indicators and controls. Figures 2 through 4 illustrate this high degree of realism of the simulated equipments. Of note is the considerable amount of piping that provides system tracing capability to the trainer. Essentially all of the equipments and machinery are simulated. In a few cases, however, real shipboard equipments such as alarm panels and ship communications equipment are used. Equipment simulation includes dynamic characteristics such as start-up, running, shutdown, casualty modes of operation, and are categorized into the following sub-system groups:

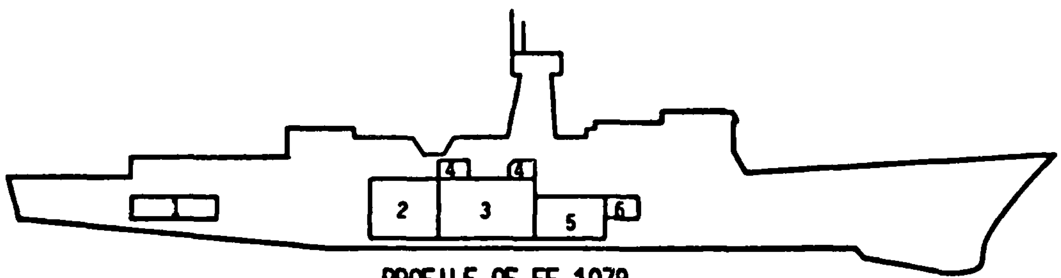
- Main Steam System
- 1200 PSI and 150 PSI Desuperheated Steam Systems
- Condensate and Feed Systems
- Main and Auxiliary Condenser Air Removal Systems
- Main Turbine Lube Oil Service Systems
- Main and Auxiliary Sea Water Circulating System
- Fresh Water Drain System
- Fuel Oil System
- Auxiliary Exhaust and Escape Steam Systems
- Lube Oil Systems
- Drain Vent and Drain Collecting Systems
- Compressed Air System
- Automatic Boiler Control Systems
- Electrical Systems
- Communications Systems
- Twin Agent (AFFF and PKP) Fire Extinguishing System

To further enhance the equipment simulations, dynamic aural cues are extensively used. These aural cues are electronically produced, and are under math model driven computer control so that full operating range and casualty sounds are realistically generated. Over two hundred speakers and four sound systems are used which




PROFILE OF TRAINER

1. AUXILIARY MACHINERY ROOM NO. 2
2. ENGINE ROOM
3. FIRE ROOM
4. FORCED DRAFT BLOWER ROOM
5. AUXILIARY MACHINERY ROOM NO. 1
6. ELECTRICAL CENTRAL
7. INSTRUCTOR STATION AND COMPUTER ROOM
8. CLASSROOM




PROFILE OF FF 1078

Figure 1. Trainer Configuration

are mounted in single or multiple quantities inside the equipments, thereby approximating very closely the sound pattern of their operational ship counterparts.

Visual effects are also used in many instances in order to produce the level of simulation necessary to meet the training objectives. These effects include such as rotating shafts on pumps, variable water levels in sight glasses, variable speed and direction of the main shaft, burner flame color, stack smoke density, and conflagration in the Fire Room. As in the case of the aural cues, the visual effects are also under math model driven computer control to assure their fidelity to the operational conditions being simulated.

All electronic equipment necessary to control the various functionally replicated machinery is located within the major machinery units in each room and the maintenance accesses to these are made inconspicuous so as not to detract from the realism of the replication. Cabling too, is either hidden from view or forms a part of some simulated ship's piping and/or cabling. In general, therefore, the internal arrangement of the trainer areas resembles very closely the configuration of the corresponding areas on the design basis ship, and any deviations necessitated by practical considerations are inconspicuous.

This attention to replication detail, comprehensive system simulation, and the extensive use of aural and visual effects creates a very realistic training environment. Consequently, not only can a broad spectrum of training in normal plant operation and casualty controls be achieved, but, in addition, such training is conducted under the constraints and limitations of a shipboard environment without the dangers inherent in that environment.

As important as a realistic training environment is to meeting the training objectives of Device 19E22, the essence of this trainer, or any trainer as a matter of fact, are the math models which drive it. Due to the uniqueness of the 1200 PSI Propulsion Plant Trainer, the contractor exercized considerable freedom in the design and development of the trainer, so as to take full advantage of innovative use of state-of-the-art simulation techniques. Consequently, it was essentially up to the contractor to decide upon the best math modeling approach to meet the training objectives.

Basically the operational requirements were that the trainer would be capable of supporting training in the Engineering Operational Sequencing System (EOSS), which includes Engineering Operational Procedures (EOP) and the Engineering Operational Casuality Control (EOCC) procedures,

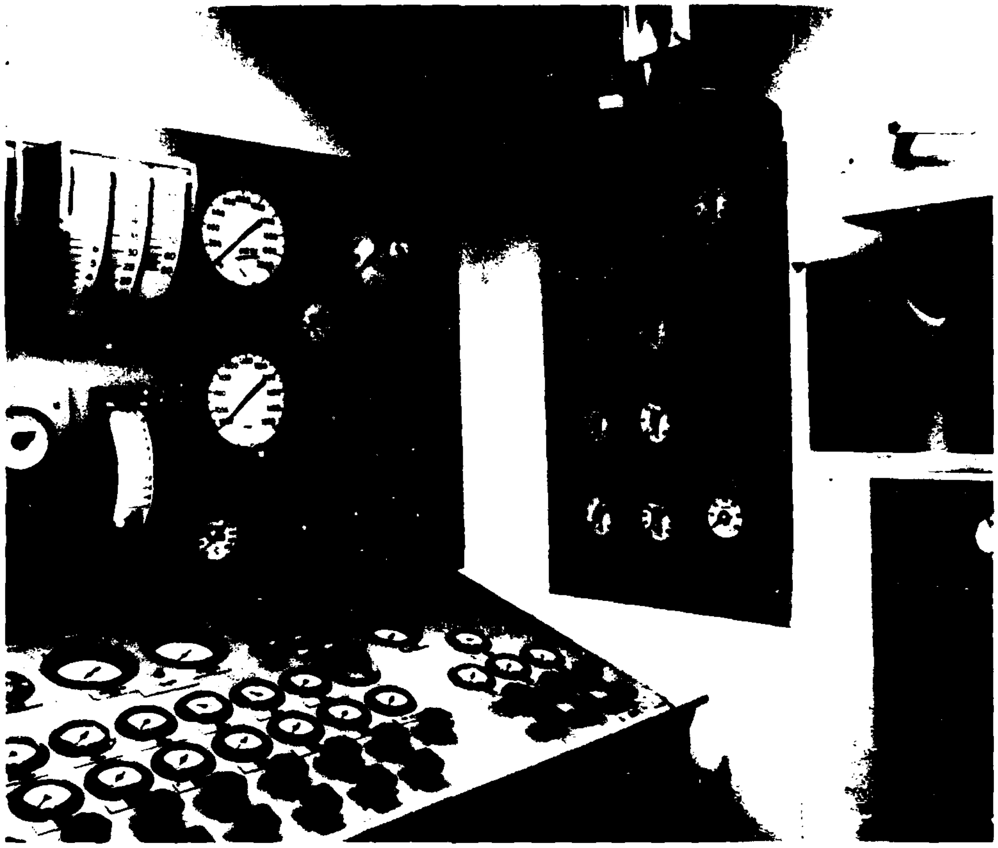


Figure 2. Fire Room Control Station

and could operate in the following four modes of operation:

- Integrated Mode - Simultaneous and interactive operation of all the engineering spaces on common training problems.
- Independent Mode - Separate and independent operation of three rooms - Fire Room, Engineer Room and Auxiliary Spaces (consisting of Auxiliary Machinery Room No. 1, Auxiliary Machinery Room No. 2 and Electrical Central).
- Record/Playback Mode - On instructor command record a 30 minute history of training data, and play it back in real time.
- Accelerated Mode - On instructor command move from one training situation and plant configuration to another in faster than real time.

The Record/Playback Mode is used for critique and demonstration purposes, and the Accelerated Mode is used to shorten the duration of operations such as lube oil preheating cycles. In actuality the Record/Playback and Accelerated Modes of operation are submodes, since they are active during either the Integrated or Independent Modes. Four trainer initialization conditions were also specified. They were:

Cold Iron - Dockside with shore steam and shore electrical power.

Auxiliary Steaming - Dockside on one boiler and ships electrical power.

Underway I - One boiler in automatic control, 15 knots.

Underway II - Two boilers in automatic control, 25 knots.

It should be noted that in Integrated Mode the entire trainer will be set to the selected initial condition, while in the Independent Mode each of the three rooms (Fire Room, Engineer Room, and Auxiliary Spaces) can be set to any of the four initial conditions. Also, although a large number of valves and controls are automatically resettable on computer command, some manual operations are required during trainer initialization. These involve such operations as insertion or removal of burners, rotary switches, and the like.

To provide this type of trainer operation, as well as support comprehensive training in plant operating procedures, it was decided early in the design development stage to math model the 1200 PSI plant from the physics point of view. By doing so the math models would recreate in essence the physical laws that govern the plant's operation, thus assuring accurate simulation of the plant dynamics during normal operation as well as casualty effects and their cascading. Furthermore,

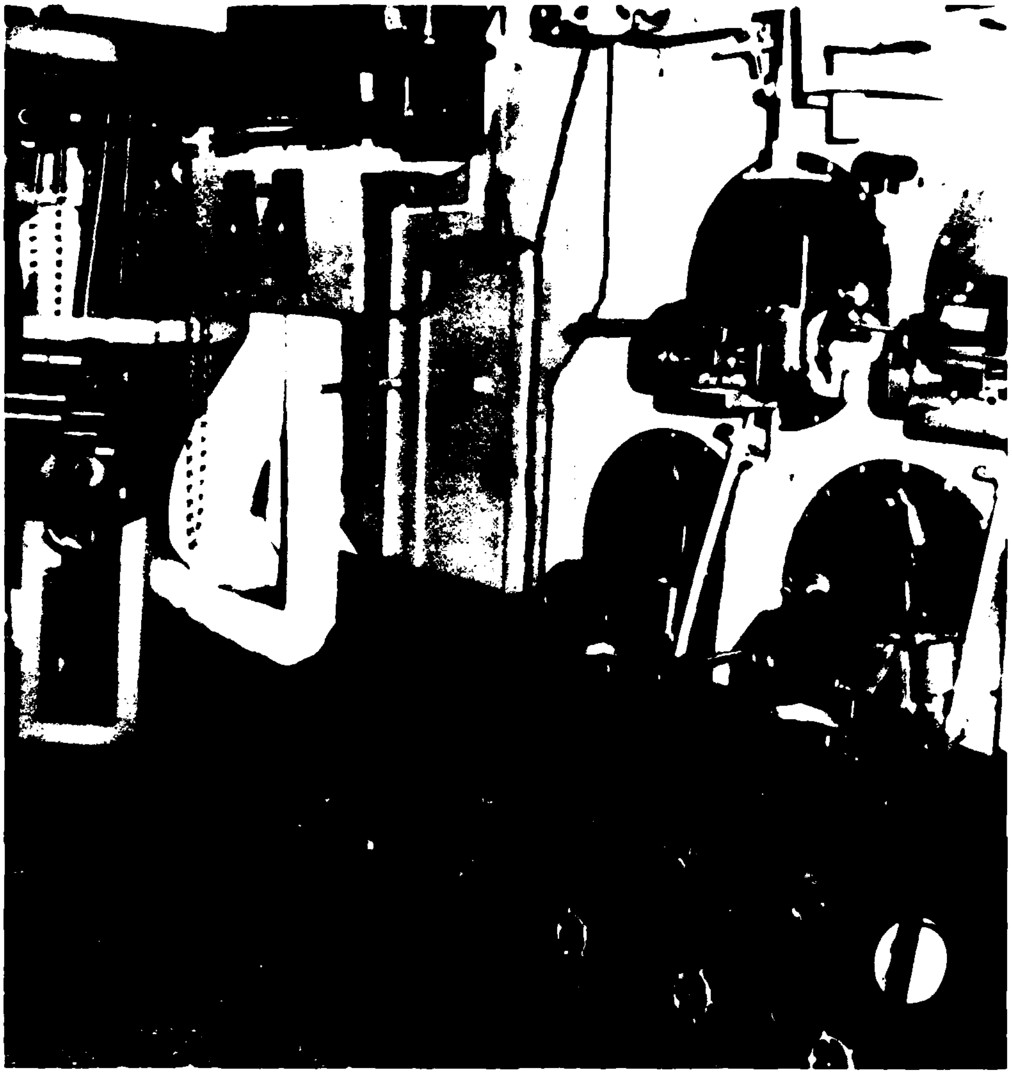


Figure 3. Fire Room - Firing Aisle

it was also decided not to model the exact detailed physical processes that take place, but rather to break down the plant into the smallest necessary system, subsystem, component, and process levels, and then use lumped parameter math modeling techniques. As a result, while the math models still recreate the physical laws at play in the plant, they are simplified considerably and have the characteristics of a black box with inputs, outputs, and a transfer function or series of equations representing the physical process. Obviously, extreme care was taken during this breakdown process to assure that all the feedback loops were accounted for and the required gage, thermometer, indicator, etc. values would be calculated.

The actual math modeling process used a bottom up approach. That is, the math models for the lowest level were developed first, then for the next higher level, and so on until the entire propulsion plant math model was developed. At each math modeling stage great emphasis was placed on making sure that all of the required input/output variables were accounted for, and that the necessary feedback loops were incorporated. One somewhat unique aspect of the math modeling process was that electrical equivalence methods were used during the analysis phase to gain in-depth understanding of the plant's operation, dynamics, and inter-relationships. Thereafter the models were written using the appropriate physics disciplines.

There were 156 casualties called out in the specification which could be inserted and removed on instructor command. They were distributed among the three trainer areas as follows:

| | | |
|---|---|---|
| Fire Room | - | 56 |
| Engineer Room | - | 29 |
| Auxiliary Spaces | - | 71 |
| | | 156 |

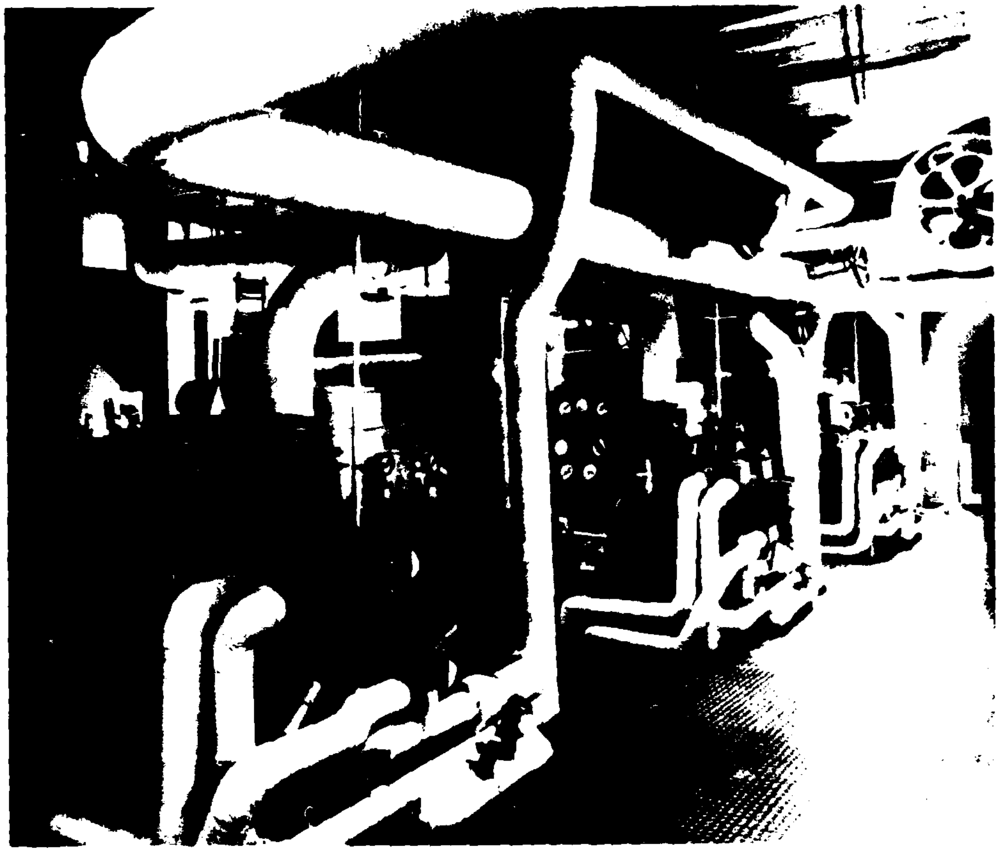


Figure 4. Auxiliary Machinery Room No. 1 Ships Service Turbo Generators (SSTG's)

Analysis of these casualties indicated that they fell into two basic categories. They were:

1. Equipment or component failures, such as "Ahead Throttle Jammed".

2. Casualties defined by symptoms, such as "Diesel Fuel Starvation".

Prior to the implementation of these casualties into the math models, the exact mode of failure had to be defined. For instance, a pump failure can be due to a broken shaft, overload, burned-out motor, etc. This is especially true in the case of the second category of casualties which are only defined via a symptom. For example, there are a relatively larger number of causes that would produce fuel starvation in a diesel engine. Furthermore, many such effects do not occur instantaneously, but rather at some rate dependent on the causing mode of failure. As a result, a specific failure mode must be defined, so that the resultant effects will be accurate both in symptoms and the time frame. Once the exact cause or failure was defined for each of the 156 casualties, the plant math models were then appropriately modified to react realistically to their insertion or removal.

Because of the fact that the plant math models were written based on the physical laws of the plant, insertion of casualties not only produced all of the necessary symptoms, but also, if appropriate, cascaded even to catastrophic proportions if timely corrective action was not taken by the trainees. Also, although all of these casualties are controllable by the instructor, a number of them will also occur as a consequence of inappropriate action by the trainees. As an example, turbine rumble will result if incorrect warm-up procedures were used. In some instances proper corrective action will automatically remedy the cause thereby canceling the casualty. In the case of the turbine rumble example, the appropriate reduction in turbine speed and the following of proper subsequent heat-up procedures will terminate the casualty whether it was initiated by the instructor or trainee action. In many cases, however, the failure causing the casualty, and therefore the casualty also, will remain in effect even if proper action was taken by the trainees. A case in point is a failed fuel oil pump as a result of a broken shaft. The corrective action in this instance is to place the standby pump on line. However, even though this action returns the plant to normal and stable operating conditions, the failed pump will remain out of commission as in the real world environment. Thus training in degraded plant operation capability is also provided, since unless the casualty is removed by the instructor, the failed pump cannot be returned to service.

To provide training capability in both the correct normal operation and casualty control procedures, another type of malfunction was added to the trainer. These were called maloperations or "MALOP", and are flagged and identified to the instructor whenever the proper procedural sequence of operations was not followed by the trainees. In those cases where the maloperation affects a critical main flow system, it is fully integrated in the math models, and if not timely corrected, is capable of producing a casualty. Typically, such maloperations are associated with the fuel oil, steam, lube oil, or sea water circulating systems. On the other hand, if the maloperation impacts a noncritical system, it will only be sensed by the math models for indication to the instructor. Maloperations of this nature are associated with vent, circulation, drain, gland seal, or other such valves. In general, MALOPS will remain in effect until corrective action is taken by the trainees. In those cases where the maloperation affects a critical system, however, the maloperation produces a degrading effect in the plant math models, and if corrective action is not taken in a timely manner, will result in a casualty.

It should be noted that the purpose of the 1200 PSI Propulsion Plant Trainer is to support comprehensive training in proper plant operation under normal and casualty control conditions and not to support training in plant maintenance. As a consequence, the functionally simulated equipments, components, and systems, as well as the math models, are limited to those relevant to plant operation. Equipments, components and piping associated with plant maintenance operations are only mocked-up in order to maintain the necessary degree of realism and to provide familiarization to the trainees. The decision as to what is plant operation related and what falls into the category of maintenance was often difficult since in many cases there is no clear cut distinction in function. Thus numerous revisions took place as a result of re-analysis conferences with Navy personnel familiar with 1200 PSI plant operations.

The drivers of the Device 19E22 simulator are the computer system with the resident math models and the Real Time Interface (RTI) system which interconnects the approximately 5,000 trainer input/outputs to the computer. The Device 19E22 computer system consists of a Harris Slash 4 computer system with 120K bytes of core memory, two 800 bpi tape drives, a 2150K byte fixed head disk, and the RTI Adapter (RTIA) whose purpose is to make the RTI system compatible with the I/O data transfer formats of the computer. Of interest also is the configuration of the simulated Twin Agent Fire Extinguishing System. It is completely independent of the main computer system is is totally microprocessor controlled, requiring only that the trainer room lights be on to operate. As a result, it is, in effect, a trainer within a trainer, and permits fire control training in conjunction with, or independent of, propulsion plant training. This, in conjunction with the Independent Mode capability, enhances the trainer up time through the availability of several modes of degraded operation.

With the exception of the Twin Agent Fire Extinguishing System trainer which is self-starting and self-contained, total control of trainer operation is provided by the Instructor Station shown in Figure 5. It is divided into three sections, as follows, from left to right:

1. Fire Room Console
2. Engine Room Console
3. Auxiliary Spaces Console

Each console consists of an interactive CRT/Keyboard terminal, communications controls, and a special purpose control panel. The interactive CRT/Keyboard terminal is used not only to display pertinent trainer room data, but also to initialize and control the trainer through the use of simple alphanumeric data entries. The only discrete controls and indicators are those that are not readily or conveniently adapted to CRT/Keyboard operation and are located on the special purpose control panel to the right of the CRT. Typically, these consists of Independent Mode controls representing outside of the room system demands and/or supplies, and instruments such as Engine Order Indicator/Transmitter. As a result, instructor workload is greatly minimized, permitting him to devote the majority of his time to training and instruction.

Communications controls for each instructor are located to the right of the CRT. These controls permit the instructors access to all of the simulated ships communications circuits for both monitoring and two-way communications purposes, as deemed necessary. In order to support Integrated and Independent Mode trainer operation, the communications system is under computer control. Thus if the Integrated Mode is selected, normal inter-space communications are possible, with the Instructor Station assuming the role of all areas outside those simulated in the trainer. In the Independent Mode, each Instructor Station console takes command of its respective counterpart. That is, the Engine Room console will assume the role of all areas outside the Engine Room. Additionally, a wireless instructor communications system is also provided. This system enables roving instructors inside the trainer to communicate with the Instructor Station to coordinate training exercises without prewarning the trainees of upcoming situations.

In addition to the critical parameter displays on the CRT's and the monitoring capability of area communications, a closed circuit TV system is used to further enhance the instructor's ability to observe and evaluate trainee performance during training exercises. This system has nine strategically located TV cameras inside the trainer area, four TV monitors on the Instructor Station, a video switcher, and a video recorder. Thus not only can trainee activity be monitored during a training exercise, but also a recording of a selected exercise segment can be made for post-training debriefing and critique which also will include all of the communications that transpired during that segment.

This then was a general description of Device 19E22, 1200 PSI Propulsion Plant Trainer, its capabilities, and the rationale behind the hardware and software design approaches that were used to ensure that the trainer could meet the requirements of its training objectives, and thus its mission. Since Device 19E22 represents a new approach to U.S. Navy engineering training, that

Figure 5. 19E22 Instructor Station

of marrying the traditional need for propulsion plant and power generation operator training with computer technology and simulation techniques, it is worthwhile to study the effectiveness of Device 19E22 in support of the Navy's training efforts, specifically in support of the training efforts of Surface Warfare Officers School Command.

Surface Warfare Officers School Command is a shore training activity operating under the command of the Chief of Naval Technical Training (CNTECHTRA). The mission of Surface Warfare Officers School Command is to provide the naval surface warfare forces, through a system of functional training, with officers professionally qualified to serve as effective naval leaders of surface ships with the ultimate goal of "command at sea." From Ensign to Captain, Surface Warfare Officers School Command provides a continuum of training for surface warfare officers at every level within the shipboard organization for all surface ships in the fleet. The following Surface Warfare Officers School Command courses employ Device 19E22 directly in their curriculums. Department Head Course. Split Tour Engineer Officer Course, and 1200 PSI Main Propulsion Assistant Course.

Engineering training is an integral part of these courses since surface warfare officers are required to possess comprehensive knowledge of surface ship propulsion plants and electrical power generation and distribution systems. Obtaining basic engineering qualification is a prerequisite for formal qualification and designation as a Surface Warfare Officer. Furthermore, since 1976, qualification as a shipboard Engineering Officer of the Watch is a prerequisite for qualification to command at sea. The existence of Device 19E22 at Surface Warfare Officers School Command underscores the importance of engineering training to the career path of today's Surface Warfare Officer.

As aforementioned, the mission of the 1200 PSI Propulsion Plant Trainer is to provide the student with the prerequisite knowledge and skills necessary to competently commence conventional steam propulsion plant qualifications. To meet this mission, and to accomplish the training objectives mentioned earlier, the training programs of Device 19E22 and the engineering curricula of Surface Warfare Officers School Command courses are structured around the FF-1052 Class Frigate Engineering Officer of the Watch (EOOW) Personnel Qualification Standard (PQS). The EOOW PQS system requires the student, as an EOOW trainee, to possess a detailed knowledge of the theory of 1200 PSI steam propulsion plant operations and of the many main and auxiliary systems of the propulsion plant. Engineering theory and propulsion plant systems training is presented in classroom lectures at Surface Warfare Officers School Command. Beyond requiring knowledge of theory and systems, the EOOW PQS system requires the trainee to discuss and/or perform certain evolutions at the various watchstations in the propulsion plant. Device 19E22 is the training platform on which students accomplish PQS watchstation requirements during normal and abnormal plant operating conditions.

Matching the realism of Device 19E22 is the fact that the students utilizing the device are given the actual EOOW PQS training materials that are employed on the operational ships themselves. Students perform watchstation items, such as placing into operation the main engine, lighting fires in a boiler, or performing corrective action for a low water in the boiler casualty, and earn signatures from 1200 PSI Propulsion Plant Trainer instructors in the EOOW PQS Qualification Card. These signatures certify that the student has demonstrated to a qualified operator a satisfactory ability to complete a specific watchstation action. The qualification card serves to document the actual watchstation training the student received in Device 19E22 and is forwarded as a record of training to the Commanding Officer of the student's future ship. It should be noted as a practical matter that Surface Warfare Officers School Command does not attempt to "qualify" students as EOOW's, for that formal, at-sea qualification is the prerogative and responsibility of the surface ship's Commanding Officer. Rather, it is reported to the Commanding Officer what qualification prerequisites were satisfactorily completed in the 1200 PSI Propulsion Plant Trainer. It is a significant fact, however, that Commanding Officers are "accepting" a large majority of the EOOW PQS line items performed in the 1200 PSI Propulsion Plant Trainer as valid for qualification purposes aboard their ships. Thus, one of the tangible benefits of the 1200 PSI Propulsion Plant Trainer is that the training received by the officer in the trainer ashore obviates, to a significant degree, the need to receive the same qualification training at sea. The end result is that officers are receiving their formal EOOW qualification earlier in their sea tour than previously experienced, and can dedicate more time towards meeting their other responsibilities. The readiness of the individual officers and, thus, the readiness of their ships, has been improved because of the engineering training these officers receive in Device 19E22.

In addition to using the actual FF-1052 Class Frigate EOOW PQS system, the students also utilize the Engineering Operational Sequencing System (EOSS) operational procedures and casualty control procedures that are identical to those that exist in the fleet today aboard most surface ships. Disciplined utilization of EOSS is stressed at all levels of the trainer's training programs. The 1200 PSI Propulsion Plant Trainer's EOSS is a credible, realistic, and workable document. It has been evaluated as satisfactory and technically correct by the Naval Sea Systems Command. It was utilized as a standard during acceptance testing of the device, and it was taken aboard actual frigates and employed to safely start up and prepare the propulsion plant for underway operations.

Device 19E22 EOSS and PQS programs are the keystones of its student training programs. These documents are no different than their shipboard counterparts and match the realism of Device 19E22 itself. Utilization of EOSS and PQS enhance the capability of the trainer to provide effective training. The capability to provide training and practice by students in the disciplined utilization of the EOSS while actually performing Engineering Officer of the Watch qualification prerequisites is an important element of the engineering training offered at Surface Warfare Officers School Command and one which was not available until Device 19E22 was placed into operation.

Device 19E22 was commissioned in November 1977 and, after a series of acceptance tests and reliability and maintainability demonstrations, was placed into operation for student training in late February 1978. Through 30 June 1980, the trainer has been utilized to provide training to nearly 3000 students, totaling over 100,000 man-hours of training. During this same period, the reliability of the device itself has been exceptionally high. In 28 months of continual daily operation, only 89 of over 6100 scheduled training hours have been lost due to unscheduled maintenance or repair activity. Both Surface Warfare Officers School Command, as the custodian of this one-of-a-kind training device, and the Navy have been exceptionally pleased with and proud of the capabilities of Device 19E22, the reliability of the trainer, the efficiency of training conducted on the device, and the training effectiveness.

When Device 19E22 was placed into operation for student training, a pilot program was established for a 1200 PSI Main Propulsion Assistant Course class. Initial utilization of the device was directed for this course because the students of this course receive no other functional, "hands-on," deckplate training, enroute to their ultimate duty station, other than that available in the 1200 PSI Propulsion Plant Trainer. The pilot program was expectedly successful. The capabilities of the device, including the realistic simulation, the magnitude of casualties, and reset capability, all combined to provide a dynamic, five-week addition to the 1200 PSI Main Propulsion Assistant Course. It was clear that more operational training could be accomplished in Device 19E22 than in a shipboard style, integrated, hot plant.

The positive results of Surface Warfare Officers School Command's training program in Device 19E22 for the 1200 PSI Main Propulsion Assistant Course led to a rapid integration of trainer utilization into the Department Head Course curriculum. Other factors contributed to utilization of the trainer by this course commencing in May 1978. Heretofore "hands-on", engineering training for students enrolled in this course was accomplished at sea aboard various units of the Naval Surface Force, U.S. Atlantic Fleet. The reduction of surface units in the Atlantic Fleet, the increased operating tempo of the remaining available SURFLANT ships, the rising fuel costs for operating ships at sea, the economic costs of per diem and travel to and from the homeports of the training ships for the Department Head Course students, and the uncertain material condition of the training ships' propulsion plants which on some occasions caused loss of training, accelerated the integration of the Department Head course into the utilization schedule of Device 19E22.

With the addition of the Department Head Course, which placed an annual demand on the trainer of 12 training weeks, to the 1200 PSI Main Propulsion Assistant Course, which required access to the trainer for 50 weeks annually, scheduling conflicts developed which required continual resolution. Thus a decision to implement two training shift operations was made in the late summer of 1978, and not only resolved the scheduling conflicts due to single shift operations, but also allowed further increases in trainer utilization, thus meeting the increasing demands on the trainer by new training initiatives of Surface Warfare Officer School Command. In the interim period of increasing the instructor staff to support double shift operations, the Deputy Chief of Naval Operations (Surface Warfare), Vice Admiral James H. Doyle, Jr., USN, established the following 1200 PSI Propulsion Plant Trainer Utilization Priority Table to resolve scheduling conflicts between current and future users of the trainer:

| Priority No. | Course/Program | Annual Requirements |
|---|---|---|
| One | 1200 PSI Main Propulsion Assistant Course EOOW Training Program | 45 weeks |
| Two | Department Head Course (CORE) Training | 8 weeks |
| Three | Department Head Course Engineering Specialty, | 4 weeks |
| | Split Tour Engineer Officer Course | 7 weeks |
| Four | Department Head Course Combat Systems EOOW | 12 weeks |
| Five | Fleet Utilization Training Program | 24 weeks |
| | | 100 weeks |

Single shift operations continued until March 1979 at which time partial, double shift training commenced. In June 1979 two-shift training commenced on a full time basis.

The 1200 PSI Propulsion Plant Trainer, because of its unique capabilities, provides distinct advantages to the students of the various courses and training programs described below. Responses of student watchstanders can be conditioned through repetition. The reset capability allows training evolutions to be repeated quickly with negligible loss of training time. Indeed, in comparison with a shipboard propulsion plant in which one evolution may take two hours to accomplish, the same evolution can be accomplished several times in the same time frame in Device 19E22. Because of the many, preprogramed casualties inherent in Device 19E22, a second advantage is that the students are permitted to observe, without fear of the consequences of non-action by the watchstanders, the actual casualty symptoms. Thus, in a controlled and safe environment without time constraints, the student can observe the immediate and long range symptoms and effects of, for example, a loss of sea water circulating water to the operating condition of a Ship's Service Turbogenerator and to the electrical distribution system. Coupled with this advantage to the student is the third advantage of being able to actually respond to the casualty symptoms themselves, to take the necessary corrective action, in accordance with Naval Sea System Command authorized Engineering Operational Casualty Control (EOCC) procedures, to bring the propulsion plant to a safe, stabilized condition, and then to restore the plant to its original operating condition. Now, instead of merely watching, the students are doing those watchstander actions required to properly operate and control the propulsion plant. Again, as described earlier, the propulsion plant, its components and systems will respond favorably or unfavorably to student watchstander actions. Thus the trainer, in casualty control evolutions as well as in normal operating evolutions, provides the classic teaching environment -- learning by doing.

A fourth advantage to the students made possible by the design of Device 19E22 is that students are afforded the opportunity to perform all propulsion plant evolutions at each watchstation of the 1200 PSI Propulsion Plant. Students utilizing the trainer are actually exposed to and receive training at all the watchstations that are manned in the FF-1078 propulsion plant during underway Condition One, or General Quarters. Thus, the trainer is manned, for training purposes, at a higher level than an operating surface ship would be for normal, routine training evolutions at sea. This manning level permits maximization of training for the student.

The fifth advantage to the student is closely linked to the trainer's capabilities which permit the selection of training scenarios that are commensurate with the abilities of the student. The spectrum of student expertise utilizing the 1200 PSI Propulsion Plant Trainer ranges from that possessed by a fledgling junior enlisted man stationed aboard ship, to the detailed knowledge and experience displayed by Lieutenant Commanders, Limited Duty Officers, and Warrant Officers. The flexibility of Device 19E22 is such that beneficial, basic individual training can be provided as easily as sophisticated team training, and, occasionally, widely disparate types of training are provided simultaneously. These instances demonstrate the independent and concurrent flexibility of the trainer inherent in its design characteristics and capabilities.

A final advantage, and perhaps the most important one in view of its long term effects, is that the trainer and its instructors provide the vehicle by which the students are schooled in the disciplined utilization of Engineering Operational Sequencing System (EOSS) procedures and formal propulsion plant communications doctrine at all watch levels. As mentioned earlier, the trainees learn to operate the propulsion plant and all its equipment safely in accordance with formal, accurate, authorized documents. They are indoctrinated into respecting these procedures and in recognizing the need for strict adherence to them. If the students gain nothing from their experience in the 1200 PSI Propulsion Plant Trainer other than a fervent application for the correct, proper, and right way in which to operate a propulsion plant in strict accordance with EOSS, then the trainer has still provided immeasurably valuable training. Students are conditioned not to rely on the memory of the watchstander or on the unsafe, unauthorized "folklore" approach to plant operations that regrettably characterized operating doctrine in the past. This zealous emphasis on EOSS is more a function of the 1200 PSI Propulsion Plant Trainer instructor staff, but without the device as the practical and realistic platform on which to practice utilization of EOSS, then the training results in this particular area would be superficial at best.

The value of the 1200 PSI Propulsion Plant Trainer is reflected in its heavy utilization schedule. There are, in fact, more training demands on the device than the trainer and its staff can accommodate. This heavy demand underscores the appreciation of the 1200 PSI Propulsion Plant Trainer and of its capabilities by Surface Warfare Officers School Command and the Navy. Training requests which have been presented to Surface Warfare Officers School Command but which cannot be regularly and formally supported by the trainer include summer training for U.S. Naval Academy midshipmen, training for Naval Reserve Officer Training Corps (NROTC) midshipmen from civilian universities, and U.S. Naval Reserve Training. Additionally, all requests for Fleet Utilization Program Training cannot be met because of higher priority commitments.

The Fleet Utilization Training Program, which places a yearly demand on Device 19E22 of 24 weeks, represents the most varied utilization of the device, and is the one program which can be analyzed in terms of the potential for expanded application of computer simulation of propulsion plant operations for the greater training needs of the Navy. Initial second shift training in the 1200 PSI Propulsion Plant Trainer was conducted in March 1979 in support of this program. This program evolved from a proposal by Commander Destroyer Squadron Twenty-Eight to utilize Device 19E22 for training the engineering crews of the ships in that squadron. This proposal was sanctioned by Vice Admiral James H. Doyle, USN, Deputy Chief of Naval Operations (Surface Warfare) and Vice Admiral William Read, USN, Commander Naval Surface Force, U.S. Atlantic Fleet, (COMNAVSURFLANT). A pilot program was established for evaluation during March through June 1979, with scheduling the responsibility of COMNAVSURFLANT. The pilot program was successful as the trainer demonstrated its ability to provide safe, energy-saving, and beneficial training in basic steam propulsion plant operations. Since March 1979, this program has provided valuable training, with tangible results, to over 650 enlisted personnel of 16 different Atlantic Fleet surface ships. Several of these ships have utilized the 1200 PSI Propulsion Plant Trainer on multiple occasions. Through June 30, 1980 nearly 14,000 man-hours of training have been provided under this program. These ships have reported that the differences in configuration between their propulsion plants and that of the 1200 PSI propulsion plant trainer have had negligible effect on the benefits and value of the training received. Fleet Utilization of the trainer has steadily increased to its present level of 24 weeks per year. This program provides training opportunities that never existed before and now ensures that 100% utilization of the device is achieved. When scheduled to utilize the 1200 PSI Propulsion Plant Trainer, a ship preselects a training program that best meets its particular desires, based upon the ship's operating cycle and its own assessment of its watchstanders' experience levels and training needs. The five training programs available to fleet users are:

1. Basic Knowledge: Individual training keyed to enlisted watchstanders without significant steaming experience.

2. Pre-LOE (Light Off Examination): Team training for watchteams with little steaming shipboard experience.

3. Pre-LOE/Proficiency Maintenance: Team Training for match teams with adequate knowledge and steaming experience; normal start-up, operate and secure training.

4. Pre-OPPE (Operational Propulsion Plant Examination)/Proficiency Maintenance Team Training with sufficient, integrated steaming experience; normal operating training plus some casualty control training.

5. Pre-OPPE/Pre-REFTRA (Refresher Training): Team training for watch teams with sufficient steaming experience; almost exclusively casualty control training.

The flexibility of the device and its multiple modes of operation easily allow a ship's crew to transition from one training program to another as it gains proficiency in operating the propulsion plant. Scheduling, as mentioned above, is the responsibility of COMNAVSURFLANT. Of interest is that when notified of dates the trainer is available for Fleet Utilization in any given calendar quarter, COMNAVSURFLANT fills the schedule within a period of a day or two. The fleet units are eager to use Device 19E22. Some units have requested several months in advance to be placed on the 1200 PSI Propulsion Plant Trainer's Fleet Utilization Schedule.

Utilization of Surface Warfare Officers School Command's 1200 PSI Propulsion Plant Trainer is maximized, limited by necessity for maintenance and daily diagnostic tests. But the demands for the trainer continue to grow, particularly from the fleet. The track record of Device 19E22 has been most impressive. Its utilization as an integral part of several Surface Warfare Officers School Command courses has added dynamic realism and excitment to these courses. It has provided training opportunities where none existed before. It has been a significant cost-saver as students no longer travel elsewhere to receive "hands-on" operator training. And, although obvious in an era of skyrocketing energy costs, it is noted that the trainer does not consume fuel oil or lube oil. Device 19E22 provides functional engineering training at a cost substantially lower than anywhere else in the Department of Navy. The 1200 PSI Propulsion Plant Trainer freed Atlantic Fleet units from training commitments to Surface Warfare Officers School Command's Department Head Course, thus allowing them to dedicate their fuel allocations for underway activities more closely aligned to their own primary mission areas and commitments. Qualification prerequisites performed in the 1200 PSI Propulsion Plant Trainer, and accepted by students' Commanding Officers, have reduced qualification periods of the students aboard ship.

The 1200 PSI Propulsion Plant Trainer has proven itself exceedingly safe and reliable and highly capable of providing efficient and effective training. Computer technology and simulation techniques, exemplified in Device 19E22, are indeed a present and viable means to meet the ever-increasing training needs of the U.S. Navy, particularly in the surface engineering community. Surface Warfare Officers School Command could not be more pleased with the positive impact Device 19E22 has had on its training programs. This enthusiasm for the present performance and potential of the 1200 PSI Propulsion Plant Trainer has been shared by many senior Navy officials, foreign Navy visitors, and interested civilian concerns who have visited Surface Warfare Officers School Command to observe Device 19E22 in operation, and, in particular, by the fleet personnel who use the device to receive the most dynamic and 1200 PSI efficient propulsion plant operator training available in the U.S. Navy today.

## ABOUT THE AUTHORS

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# NUCLEAR SUBMARINE MACHINERY CONTROL ROOM TRAINING SIMULATORS AND THEIR USE IN TRAINING ENGINEERING WATCHKEEPERS

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## ABSTRACT

The training requirements for the nuclear submarine engineering watchkeeper are stringent. The Royal Navy uses simulators for initial and continuation training. A typical submarine propulsion system is described. A typical simulator is also described with reference to the hardware provided, the degree of simulation and the training facilities provided. Training on the simulator is compared with training on actual plant, and the relative advantages and disadvantages are highlighted. The use of the simulators in the overall training programme is described, commencing with ab initio training where the use of the simulator is complementary to classroom instruction, through qualification and licensing of operators where operation of the simulator constitutes part of the qualifying examination, to continuation training where the simulator is used for co-ordinated team training. The programme of development of a family of simulators and their use by the Royal Navy is described. Some of the lessons learned during this programme are discussed with pointers for future simulators.

## THE TRAINING REQUIREMENT

It is common for nuclear submarines to be away from base for many weeks at a time, with no nuclear repair facilities at ports of call. Consequently, the burden of support is placed on the crew. As crewmen must, therefore, be totally familiar with both the operational and the maintenance aspects of the plant, intensive training is directed towards this total knowledge. Safety, correctness and confidence are instilled as essentials throughout the stringent training of these nuclear submariners.

Training in maintenance and operation, whilst complementary, require different equipment. Maintenance training usually requires practice on actual equipment; however, if the prime equipment is used, it is probable that the full range of operations could not be readily presented without perhaps endangering the plant or the personnel.

Practice in real-time operations (without the expense, hazards or restrictions of a real plant) is therefore most readily afforded by the use of simulators. The Royal Navy uses simulators for both the ship's control room and the engineering plant control room (Machinery Control Room) the latter being the subject of this paper. Practice is essential; initially to demonstrate control of the plant within its normal operational boundaries and subsequently to provide experience of various degrees of emergency operations resulting from incidents such as plant failures and maloperations by other crew members. Used effectively, simulator training will engender confidence through practice and familiarisation of all situations, including those which are expected to be rarely encountered on the operational vessel.

## THE BOAT PROPULSION SYSTEM

A typical boat propulsion system is illustrated in Figure 1.

The heart of the power plant is the pressurised water reactor. This is a collection of fissile uranium fuel elements arranged in a shielded pressurised vessel. The fission rate in the reactor is controlled by use of special rods which are inserted into the fuel to absorb fission neutrons. The reactor, steam generator, pressuriser, coolant pump and pipework form an enclosed loop referred to as the primary circuit. Water coolant is pumped round the circuit, passing through the reactor where it extracts heat from the nuclear fuel elements.

The purpose of the pressuriser is to maintain the coolant water at a steady state.

Electrical heaters, mounted inside the pressuriser vessel, are used to maintain a steam bubble within the pressuriser vessel thereby maintaining the pressure of the coolant system at the correct saturation pressure to achieve this steady state.

After passing through the reactor the heat coolant circulates through the tubes of the steam generator, where its heat is used to convert the low pressure water outside the tubes into high quality steam. The now cooler primary water is circulated through the reactor to continue the heat exchange cycle. The complete primary circuit is housed in a specially shielded reactor compartment to contain harmful radiations.

Steam from the secondary side of the steam generator is used to drive the main propulsion turbines which, through reduction gears, drive the propeller shaft. On leaving the main turbines the spent steam is condensed in a sea water cooler and returned to the steam generator as water to begin the secondary cycle once again.

Steam is also used to drive turbo-generators which provide AC electrical power. DC power requirements are met by motor generators or batteries. Spent steam from the turbo-generators is recycled in the same way as that from the main turbines.

Sophisticated automatic and manual controls provide the controlling means for both the reactor and steam generator facilities and also for the secondary and support facilities. In addition elaborate electronic and mechanical features assure the safety of the nuclear reactor at all times. These controls are mounted on a console structure situated in the Control Room. It is this control complex which is simulated.

## THE SIMULATOR

A typical Machinery Control Room Training Simulator complex is illustrated in Figure 2. The complete complex comprises the following three major subsystems:-

1. Machinery Control Room.
2. Instructor's Console.
3. Computer and Interfaces.

The first two of these subsystems comprise the instructional complex; the latter, which is situated in a separate room, the simulator control complex.

The Machinery Control Room is an exact replica of the Ship's Machinery Control Room with the hull skin removed. The lower area between the ribs is open thereby affording the Instructor the means to observe directly the operation of the trainee crew. All controls, instrumentation and equipments normally visible to and operated by the crew are fitted. The appearance, location and operation of these correspond to those which exist in the actual submarine. Two free-standing loudspeaker units, for the reproduction of simulated noise effects, are situated one at each end of the main console, though not directly visible to the trainees.

The Instructor's station comprises a console and a raised platform which enables the Instructor to overlook the interior of the Machinery Control Room and observe trainee action. In addition, there is an observation platform whereby personnel not directly involved in the training exercise can observe the proceedings. The console contains all necessary instrumentation and controls which enable the Instructor to initialise the training exercise, to monitor trainee operation, where necessary to act as an out station operator, to provide override of the Machinery Control Room controls and to induce faults in the various simulated submarine systems.

Situated in a separate room is the computer/ interface complex which comprises the following major items:-

a. A general pupose digital computer.

b. An interface cabinet.

c. A junction box.

The general purpose digital computer comprises central processor, core store memory modules, magnetic disc backing store and control station for systems' initialisation and software maintenance. System modelling is by core resident software programs.

The interface cabinet contains the circuitry which connects the Machinery Control Room controls and display instrumentation (analogue and digital signals) to the computer. It also contains the circuit necessary to synthesize the audio effects, the production of which is under software control.

The junction box routes signals between the interface and the Machinery Control Room controls and displays.

From an engineering point of view, Table 1 summarises some of the significant statistics of the simulator.

Table 1

SIMULATOR STATISTICS

| | |
|---|---|
| Total operational software program size | 80k words |
| Typical number of executed instructions per second | 250k |
| Number of digital input signals | 750 |
| Number of digital output signals | 600 |
| Number of analogue input signals | 65 |
| Number of analogue output signals | 150 |
| Total number of Instructor input faults | 120 |

The following two sections of this paper give an outline description of the simulator with specific references to the two major operational complexes; the Machinery Control Room and the Instructor's Console.

## THE MACHINERY CONTROL ROOM

The simulator provides full simulation of the ship's systems as described below:-

### Primary systems

The primary systems are those associated with the nuclear reactor, the heat source of the steam propulsion plant:-

1. The Reactor

   The reactor simulation is based upon a point source two group model, which relates neutron power and primary coolant temperatures to reactor control rod position. The model used takes into consideration all relevant effects such as reactor core age, time since shut down, previous operating power, operating temperatures and xenon poisoning levels. In addition, the model takes into account rod worth characteristics and instructor induced fault conditions such as stuck control rod, single or group rod dropped and instrumentation channel errors.

2. Reactor Thermo Dynamics

   This model simulates the transfer of heat from the reactor fuel plates through the pressurized coolant loops to the steam generators; the effects of the main coolant pump combinations and the state of main isolating valves being taken into consideration.

3. Pressurizer System

   The pressurizer accommodates variations in primary system pressure due to changes in secondary plant power demand. Because of the extremely high manoeuvrability of the submarine, these changes can be both large and rapidly occurring.

   The pressurizer system model simulates the relationship between changes in primary circuit temperatures and level changes within this pressurizer. In addition, simulation of the heater and sprayline control logic is included together with their dependence upon the electrical system. It should be noted that an interaction exists between some of the ship's systems (the reactor, pressurizer, steam demand and power electrics) which are all simulated in real time. Instructor induced faults can also be inserted; these include indicated parameter errors, control override, fast and slow primary coolant leaks, and various induced alarms.

4. Associated Systems

   Typical such systems simulated are the emergency cooling system, the coolant make up, discharge and treatment systems, the coolant pump fresh water cooling systems.

### Secondary systems

The secondary systems are those associated with the steam propulsion plant and include:-

1. Steam generators and main steam distribution systems.
2. Feed water and feed water regulation systems.
3. Main engines.
4. Turbo generators - for main electrical power generation.

Associated auxiliary systems, typical of which are the circulating water systems, the extraction systems and the lubricating oil systems, are also simulated.

### Electrical systems

These comprise:-

1. Battery.
2. AC/DC motor generators.
3. Turbo generators.
4. Shore ac electrical supply.

All circuit breaker inter-coupling and protection features are fully simulated.

### Ship's support systems

Air conditioning, hydraulics and other vital systems are also simulated.

The ship's systems form an integrated closed loop complex in which a change of state in one subsystem is reflected through other subsystems. It is this interaction between the subsystems which makes not only the design of the simulator but also the training requirement the demanding tasks that they are.

## THE INSTRUCTOR'S CONSOLE

The facilities provided at the Instructor's Console allow the Instructor to perform three main functions. These functions comprise the following:-

1. Monitoring

   The Instructor has a view of the Machinery Control Room through the cut out in the roof section so that he can monitor the actions of the Operators. Meters which are not easily visible to the Instructor through the cut out section are repeated on the Instructor's Console. These meters and magnetic indicators are grouped in a manner similar to those on the Machinery Control Room panels.

2. Acting as an 'Out-Station' Operator

   A Machinery Control Room operator may

call for an action by a crew member who is normally located elsewhere in the submarine. To cater for this, and to enable the Instructor to make the normal replies to the operator, 'out-stations' controls are provided. Typical such functions are associated with the main machinery space, the electrical systems (such as running up the Diesel Generators) and the control room.

3. Defining and Controlling Plant Conditions

   By the injection of plant initial conditions and the injection of system and instrument faults the Instructor can define and change plant states prior to commencement of and during a training exercise. Thus the reactor initial conditions, comprising core age, power level of previous operation, time since shut down, desired pressurizer and heat exchanger levels and primary loop temperatures and pressures are specified by the Instructor as system initial conditions. A comprehensive range of faults (a total of 120) may be injected by the Instructor.

Additional realism is achieved by the inclusion of simulated audio effects, the characteristics and onset of which are produced in response to operator actions. Such effects included in this category are:-

a. Audio associated with the running up of Diesel Generators.

b. Circuit breaker operation.

c. Instructor induced steam leaks.

d. Rod drive transmitter.

Other ambient effects such as temperature, humidity and vibration are not reproduced.

An instructional facility provided with the simulator is that of record/replay. This facility enables the Instructor to select the whole or any part of an exercise for recording and subsequent replay for debriefing purposes. The display parameters on all meters and the state of all indications are recorded at fixed intervals. These recordings can be replayed at different rates specified by the Instructor (faster or slower than real-time) on to the Machinery Control Room instrumentation. The Instructor can start the replay at any point in the recording. Using a faster than real-time replay long term transient effects can be readily demonstrated. Using the slower than real-time replay high speed effects, such as the relationship between circuit breaker operation and electrical generator states, can be demonstrated.

## THE ADVANTAGES OF SIMULATOR TRAINING

Most of the advantages of using a simulator for training purposes can be summed up by saying that it is relatively inexpensive, much safer and allows training for emergencies which cannot be conducted on a real plant. It is significantly safer to train the watchkeepers on the simulator than to train them on the prime equipment. The savings in cost are the consequence of many features, but predominant among them are the low capital and running costs of a simulator by comparison with the equivalent figures for a real set of machinery. Not only are the operating costs minimal, but the simulator can be operated continuously and exactly repeatably for year after year, whereas the real plant must necessarily be withdrawn from service for refitting at regular intervals. Furthermore, variants of one simulator representing several submarines makes for even greater savings in cost.

Further cost savings result from the ability to locate a simulator at any convenient place, such as within a training establishment, or even to make it transportable. In addition, the simulator can be brought to any desired plant state in a few seconds, whereas a major change of state may require several hours with real machinery.

The ability to train for hazardous or emergency conditions, which is another major advantage of simulator training, is out of the question when training with a real plant. Since it is of crucial importance that the watchkeepers can recognise and respond correctly to emergency situations, which by their nature are encountered only very rarely in real life, the value of simulator training in this context can hardly be overstated. Not only can such exercises be carried out they can also be repeated as often as desired.

It is worthwhile at this point to highlight two features commonly found in all good simulators. One is the facility to change the pace of the action to permit recognition of the constituent stages, without diminishing the logical validity; in the limit this may include single stepping, or stills, or even freezing the simulation state at any point to allow discussion. The other feature is the accurate repeatability of the simulation when generated by a computer program. It is highly unlikely that a plant transient or incident can be accurately repeated on demand on a real plant, but because the 'plant' of a simulator is a programmed computer the repeatability is total.

A particular advantage is that operator training can be started before the real plant is available which, apart from savings in time, certainly makes the initial operation of a new type of plant safer and easier and provides a pool of operators as part of the plant commissioning team. Adaptation of the mathematical model may be necessary once the operational characteristics of the plant are available, but this usually is more fine tuning than significant re-programming.

Experience has shown that the early availability of a real-time training facility is of significant advantage and has also shown that the optimum lead time is about one year. This provides an adequate period for basic operator training for a new plant; if a longer period is programmed then the computer programs and the detailed engineering of the control panels may well be subjects of change during the period of simulator construction. In practice a design freeze at, say, a one third stage of the simulator build programme will produce a simulator of sufficient accuracy for initial training which can be easily modified when the true characteristics are known. A simulator takes of the order of two years to construct, including commissioning. This is much shorter than the time required to build and commission a nuclear submarine or any other plant of similar complexity. Consequently, the simulator build can be started at a point where the submarine is well defined and still be completed in time to provide adequate training prior to testing the real power plant.

Thus it can be seen that genuine advantages are derived from the use of a simulator, some of which can be fairly readily quantified in terms of cost or timescale with others less tangible.

## THE DRAWBACKS OF SIMULATOR TRAINING

With such a catalogue of benefits to be obtained from simulator training it would be surprising if there were not some accompanying disadvantages. There are, of course, some problems. The chief one is that, no matter how perfect the simulator may be, the trainee retains some awareness that it is not the real thing. His motivation to do well is thus likely to be less powerful than if his survival, or at least his comfort, is dependent on his performance.

This is a psychological effect and no doubt varies in its significance between individuals, but it is always present to some degree. Not only can his motivation be affected by this factor, but there can perhaps be an attitude of recklessness induced which may be summed up as "It's only a simulator, so let's do this and see what happens'. However, this attitude may not be altogether bad.

The second difficulty is that all simulators have less than complete realism. In real life, operators obtain their total information input from some "unofficial" sources, as well as the "official" ones. For example, the fall in pitch of the hum from a ventilating fan may provide a more sensitive indicator of falling supply frequency than a frequency meter, and is likely to be noticed at least as rapidly. A training simulator is unlikely to reproduce all the "ambience" of the real life situation, even if an attempt is made to do so, and to that extent, a simulator is unreal. More elaborate simulation can always be provided, of course, but only at greater cost and it is never clear at what degree of realism the most effective training is achieved, especially as realism is somewhat subjective.

## THE ROLE OF THE SIMULATOR IN OPERATOR TRAINING

### Initial training

Simulators may be used through all the stages of training and refresher training of the operators. In the initial stage it is useful to demonstrate visually the concepts taught in the classroom.

It is essential to provide practice but also desirable to eliminate hazard to the plant. Perhaps this can be compared with learning to drive an automobile where basic manoeuvres or manipulations produce a certain fear in the Instructor, especially if he also happens to be the vehicle owner. Simulation in this stage also aids the appreciation of interactive systems which the curriculum inevitably treats serially. In short, topics which are taught separately, lesson by lesson, can be presented simultaneously if that is how they occur on the real plant. Reference has been made earlier in the paper to the total repeatability provided by simulation, and use of this feature, coupled with record/replay facilities, makes an essential contribution to the transition from classroom to operational training.

Thus classroom and simulator instruction can be complementary in the initial stages of training.

### Qualification and licensing of operators

The next stage of training is the transfer from the general application of the basic theory to the more detailed instruction on the plant, or submarine, to which the partially qualified operator is drafted. Any one simulator installation can be fairly readily adapted to accurately represent each specific vessel of a flotilla. Although in some instances this may necessitate the use of interchangeable sections of control or display panels it may also only be necessary to feed into the computer a variant of the program which differs parametrically or logically.

Perhaps the simplest example is of two or more similar plants with slightly different protection systems operating at different trip values. Even if panel changes are involved this can usually be effected speedily (certainly compared with the real plant) with functions re-routed by the computer program addresses.

This stage of specific training usually concludes with formal qualification (or licencing) for the allocated watchkeeping position, where a period of intensive operation in the simulator constitutes a part of the qualifying examination.

The logical extension of this stage is the training and formal qualification for other positions within the crew.

Continuation training

Training is not only a phase which precedes qualification and practice. It continues throughout the operational life of the boat to maintain the high pitch created, to introduce new situations presented by plant modifications or experiences learned across the fleet and to create and support the performance as a team. Throughout this phase emphasis is placed on co-ordinated team training, where collective responsibility and the interdependence of the various watchkeeping stations can be demonstrated on the simulator in a manner which it would be extremely difficult to achieve other than on a plant.

The periodic, or refresher, retraining of teams of qualified operators, particularly after submarine refits, and the requalification after a specified period of time may also utilise the simulators and it is at this and the previous stage that intensive emergency operations are practiced.

Thus the simulators play a vital part in every stage of training and qualification of operators from basic principles to regular requalification. Moreover they can be used effectively in the assessment of operational drills, the ergonomic effectiveness of new control system designs and the validation of operational situations postulated in safety assessments.

## THE SIMULATOR PROGRAMME

The Royal Navy has been using simulators for the purpose of training Machinery Control Room watchkeepers on nuclear submarines for more than a decade. The simulator procurement programme began in 1966 with the placement of the order for the Dounreay based simulator. Prior to this date training had been undertaken on a shore based plant which fulfilled the dual roles of research and development and training. The first refit of this prototype plant necessitated the introduction of a simulator to take over the training aspects. At this time the full potential of simulation techniques was not recognised and as a consequence a general purpose simulator was designed; it was thus not fully representative of any particular ship type. Notwithstanding this its operational usage more than proved the case for sucn training simulators and consequently contracts were placed for the second and subsequent simulators.

There is now a total of six Machinery Control Room training simulators either in service or under build. This illustrates a long term commitment by the Royal Navy towards the use of training simulators. There is every indication that this commitment will continue with the procurement of additional simulators in parallel with predicted fleet expansion. By this means the Navy will maintain, at minimum cost, its customary very high standard of operational readiness of its watchkeeping crews.

A great deal of experience has been accrued over the span of this procurement, development and manufacturing programme. Some aspects of this experience will be outlined from the point of view of lessons learned and consequent pointers towards improving future simulators. It is not claimed that these conclusions in any way represent new discoveries but that they merely confirm existing good practices in simulation development and procurement.

From the manufacturer's point of view experience in the design of this series of simulators has re-emphasised the basic requirement for the assembly of the correctly qualified design team and the production of a definitive requirement specification. In this respect a happy marriage between the skills of Rolls Royce and Associates Limited (RR&A) and Marconi Space & Defence Systems Limited (MSDS) was achieved. Thus RR&A provided the skills of the actual plant designer, the mathematician, and the experienced plant operator. These were complemented by the MSDS specialized skills in respect of simulator design and in particular computer hardware and software.

Bearing in mind that the basic requirement was for a simulator for training Navy watchkeeping personnel the RR&A experienced plant operators fulfilled the vital role as the expert co-ordinator between the simulator manufacturer and the eventual user. In this way problems of interpretation and of a subjective nature were in most cases resolved prior to involvement of the simulator manufacturer.

From the user's point of view, that is from the Instructor's point of view, this has once again confirmed the need for exceedingly detailed and careful analysis of the use of the simulator as a training tool in the way in which this affects the provision and layout of Instructor facilities. Even though each succeeding simulator has these facilities designed into it as a result of the accumulated experience on preceeding simulators there is still room for improvement in this area. This leads us to consider the use of alternative devices for Instructor control and display. Whereas existing simulators have, by good Navy tradition, such things built to "battleship standards", a more compact and cost effective and operationally more effective facility might be achieved by the use of visual display units and keyboards. This is an area which might bear fruit on further consideration.

Also from the user's point of view more consideration might be given to the use of the simulator for purposes other than for training; for example, such a simulator might be used for the trial and evaluation of new operating procedures. The viability of this is obviously related to trainee throughput and simulator availability and is also critically dependent upon the sophistication of the system modelling. Consequently, this requirement must be specified at system definition phase when the degree is being determined.

## SUMMARY

From the trainee's point of view, undoubtedly a very high standard of training is being achieved with the simulators. However, this should not lead to complacency - the attitude "what we have works well, so let's make the next one the same" must, though seemingly attractive and comforting, be resisted. Where the achievement of a high degree of realism in any simulator is expensive and obeys the law of diminishing returns it could be most profitable to investigate a methodology whereby the optimum degree of realism can be determined. In these circumstances we might ask such questions as: "Does the simulation of secondary effects such as noise significantly enhance the training transfer? Would the inclusion of additional ambient effects such as temperature, vibration and so on, significantly increase the training transfer?" Indeed a very much more fundamental question might be asked: "Bearing in mind that the basic requirement is the training in a set of specific skills, is the best training device for achieving this one which attempts totally to reproduce the boat environment?"



## ACKNOWLEDGEMENTS

The authors wish to thank the Technical Director of GEC-Marconi Electronics Limited for permission to publish this paper.

The authors also gratefully acknowledge the active support and assistance of the UK MOD(N) Directorate and staff during the simulator programmes and also in the preparation of this paper.


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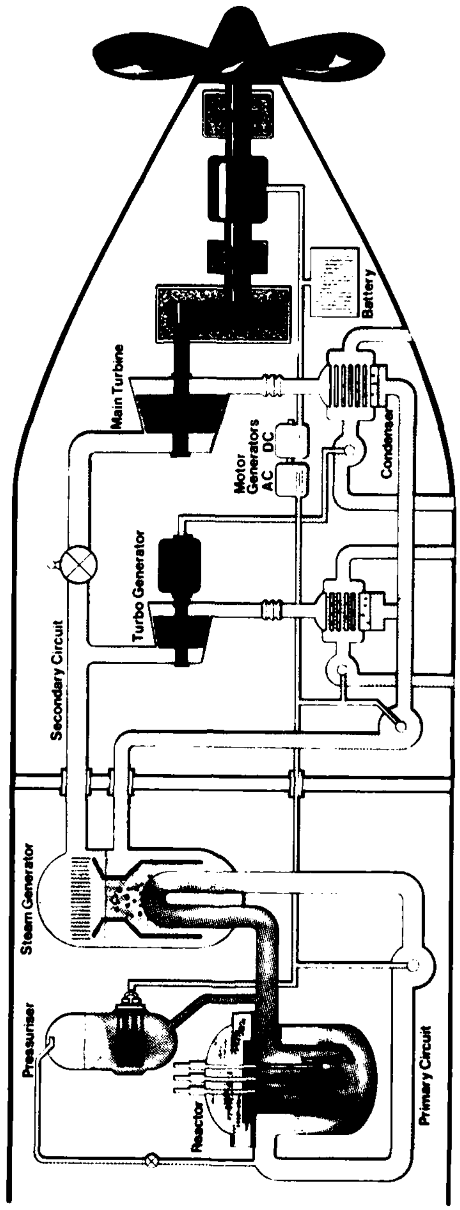
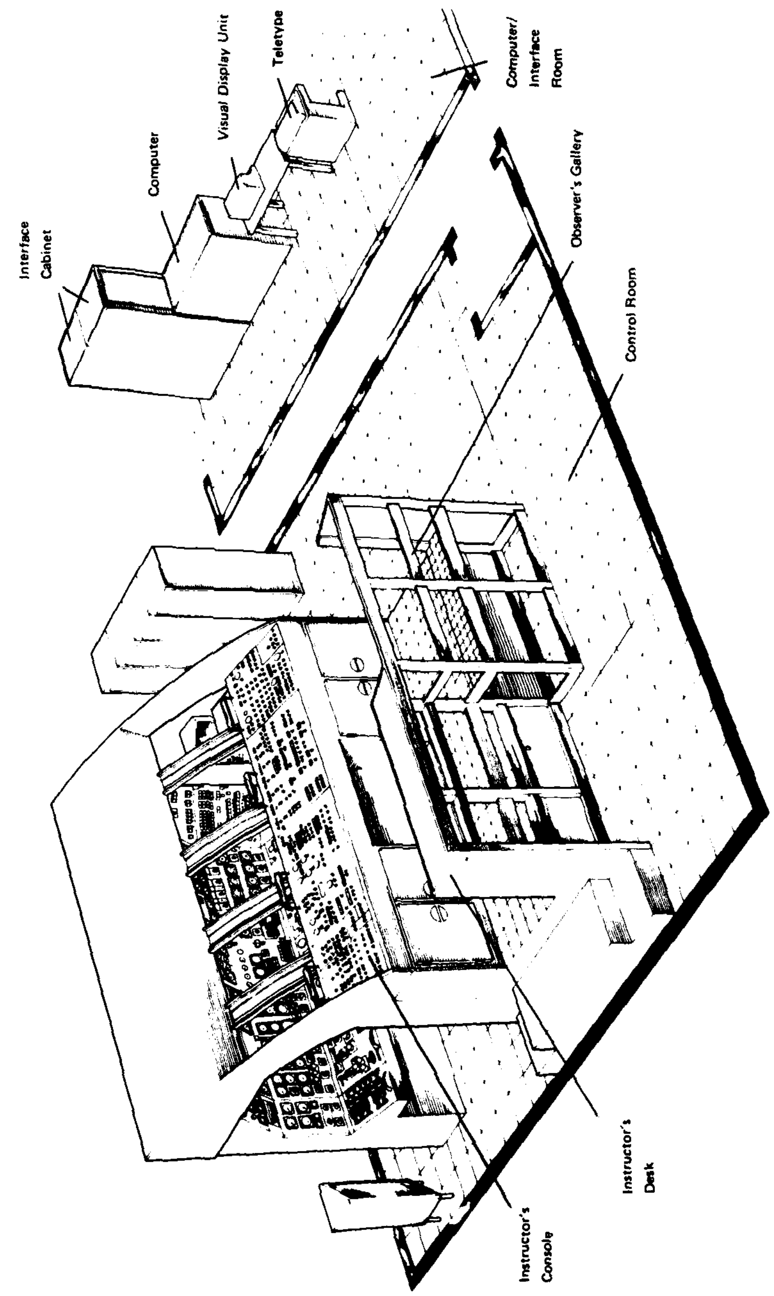



Boat Propulsion System

Figure 1




Machinery Control And Computer / Interface Rooms - Overall View Figure 2

# DEVELOPMENT OF SMARTTS TRAINING TECHNOLOGY

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## ABSTRACT

The Submarine Advanced Reactive Tactical Training System (SMARTTS) will be the "training subsystem" of the 21A Series Submarine Combat System Trainers. SMARTTS is the result of a series of research and development investigations directed by the U. S. Naval Training Equipment Center investigating the application of advanced training technology to submarine tactics training. SMARTTS is expected to greatly enhance the tactics training process by improving the quality and quantity of tactics training and by correcting current deficiencies of the tactics training system. The advanced training technology embodied under SMARTTS will present emerging concepts and capabilities that should be initially developed as an integral part of every simulator-based training system. The paper summarizes the SMARTTS program placing particular emphasis on the development of the SMARTTS characteristics as a result of a modified instructional systems development analysis. The SMARTTS characteristics, which are primarily implemented via software additions to the simulator programs, are applicable to virtually every simulator-based training system. SMARTTS will be a major addition to the Submarine Combat System Trainers; it represents a milestone in that it is a major subsystem, emphasizing advanced training technology as an integral part of the training device.

## INTRODUCTION

The Submarine Advanced Reactive Tactical Training System (SMARTTS) is the training subsystem of the submarine tactics training device. SMARTTS has been specifically designed to provide training assistance features to the 21A series Submarine Combat Systems Trainers (SCSTs) and thereby enhance their training effectiveness. SMARTTS is designed to address individual and team training requirements for the SSN MK 117 fire control system and AN/BQQ-5 sonar, and the SSBN MK 113 Mod 9 fire control system and AN/BQQ-2 sonar. SMARTTS is a strap-on subsystem, the preprototype of which is currently being installed on the 21A41 SCST, Norfolk, Virginia. An evaluation of the training effectiveness of the 21A41A SCST (i.e., with SMARTTS) will be accomplished in the operational training setting immediately following completion of the preprototype installation.

## BACKGROUND — DEVELOPMENT OF SUBMARINE TRAINING TECHNOLOGY

The U.S. Navy submarine forces are experiencing accelerated transition to significantly improved, although increasingly complex, weapons and tactical command and control systems for both SSNs and SSBNs. These technological advances are matched by expanding submarine mission roles and tasks in tactical and strategic warfare, and other classified operations. Enhanced operational performance of weapons, fire control, sonar, periscopes, electronic support measures, and other sensors, together with advanced ship characteristics, places heavy emphasis on responsible tactical command and control. High speed digital data processing, coupled with computer analysis of multiple-sensor inputs requires highly developed operator visual and interpretive skills. These skills must be supported by the operator's ability to make complex tactical decisions. The number of personnel directly involved in command and control within the submarine's tactical decisionmaking processes has likewise increased with fleet introduction of new technologically advanced systems. These developments are placing increasing demands on submarine tactical and operational training to promote operational readiness.

Note: The authors are solely responsible for this paper; it does not represent U. S. government positions or policy.

The overall submarine tactics training system, whether providing formalized team training in shore-based attack centers or individual on-the-job training at sea, principally exists to support submarine force operational readiness. Submarine Combat Systems Trainers (SCSTs) for SSNs and SSBNs are located at all major submarine operational training centers. Simulation methodology and equipment retrofits provide the latest in onboard equipment developments for the SCSTs. Collectively, these SCSTs represent the primary component of the submarine tactical training system.

Tactics training presently satisfies a wide range of requirements, from the submarine officer basic, indoctrination, and advanced courses (SOBC,SOIC, and SOAC) through advanced levels in the prospective executive officer (PXO) and the submarine force commander's prospective commanding officer (PCO) courses. Training within these courses spans individual through team contexts. SCST utilization includes these formal shore-based courses, as well as support for ships in refresher and predeployment training. Advanced training technology to enhance the training process is required for these SCSTs.

Until recently, with the advent of digitally processed sonar (e.g., AN/BQQ-5) and fire control (i.e., MK 113 Mod 10 and MK 117) information and advanced weapons (e.g., MK 48 torpedo, Tomahawk), submarine tactics had changed little since World War II. This was generally true of both the hardware systems and the tactics employed in their use. Although some hardware changes did evolve, they were primarily the result of better hardware designs to perform the same functions. Several notable exceptions were the MK 51 analyzer and several plotting techniques (e.g., Eklund ranging) which were developed during this period. Nevertheless, those changes that did occur represented a steady evolution in submarine tactical capability. During this period, the Naval Training Device Center (NTDC) (which is currently the Naval Training Equipment Center — NTEC) had initiated a variety of research and development efforts investigating the improvement of training technology. With several notable exceptions, the majority of these efforts were concentrated on surface and aviation Navy training devices. Much of the early work investigating tactics training in the submarine force was performed in a series of NTDC/NTEC-studies by Sidorsky and others during the 1960s.[1,2,3] Sidorsky's work centered on tactical decisionmaking, resulting in a decisionmaking taxonomy that has been the basis for several applications of decisionmaking theory in the operational environment. Hammell and Mara[4] used the taxonomy as the basis of an approach to submarine tactical decisionmaking training. Observations on SCSTs, discussions with naval training and operational personnel, and analysis of at-sea exercise data indicated the potential of this approach to training. A later effort by Pesch, Hammell, and Ewalt,[5] used the Sidorsky taxonomy as one level of a multileveled approach to submarine officer tactical decisionmaking training. This latter approach has been used successfully to train merchant ship masters in decisionmaking regarding the international rules-of-the-road.[6]

A second major development by Sidorsky was the TACTRAIN device, an individualized CRT-based tactical decisionmaking trainer. It was developed to train advanced tactical decisionmaking to senior submarine officers. TACTRAIN introduced several new concepts to the submarine training community. It provided individualized training to senior officers; it was based on a CRT driven by a computer in a war-gaming format; it enabled a wide range of flexibility in controlling the training process; and its model functioned on the basis of probability estimates (e.g., probability of counterdetection). At that time, however, the operational submarine fire control system (e.g., MK 113 Mod 6) did not deal with probability estimates or display such data on CRTs.

The submarine fire control systems in use during the mid-1960s were basically similar to the earlier fire control systems in function, although somewhat different in hardware layout. The Submarine School (SUBSCOL) in New London was charged with training officers entering the SOBC. The traditional approach had been to provide individualized training on the attack director, followed by team training on the SCST. A group of individual torpedo data computers (MK 4) were used for individualized training with regard to the older basic submarine fire control systems (MK 106). Individual training devices, however, were not available for individualized training on the newer MK 75 attack director used in the MK 113 fire control system series. A request by SUBSCOL for a group of individualized MK 75 attack director trainers prompted NTDC to initiate an investigative effort to determine specific submarine officer requirements for tactics trainers. The intent was to approach the tactical training issue by systematically analyzing tactics training to determine the then current and future training device requirements. During the late 1960s, a variety of fundamental tactics and hardware changes were in the developmental stage (e.g., digital sonar hardware, digital fire control hardware, and MK 48 torpedo). These advances were to have a profound impact on submarine tactics.

The investigation, which initially considered basic level training and was later expanded to include advanced officer training and all SCSTs, identified a variety of areas in which the tactics training process could be improved.[7,8] The identification of the need for a variety of individualized training devices together with the advanced knowledge of the computer/CRT-based fire control systems under development at that time, resulted in the recommendation for the Generalized Individual Trainer. The recommended Generalized Individual Trainer was to be a general purpose computer-based CRT console that could be readily configured to meet the wide variety of training needs; furthermore, this device could incorporate advanced training technology concepts. More importantly, these investigations found that the current SCSTs lacked fundamental training technology capabilities which had the potential of greatly enhancing the training process. The authors concluded that if these capabilities were incorporated into the training device when initially developed, they would represent a relatively small increase in cost. A variety of training-related capabilities were recommended to be installed on the existing SCSTs. These recommendations addressed three aspects of the training system: 1) trainee information, 2) instructor support, and 3) training system management. The SMARTTS characteristics represent the development and application of these earlier developed concepts.

Hammell et al.[9] carried the investigation a step further by developing a performance measurement approach for submarine tactics training. The nature of the submarine tactical problem (i.e., decision-nmaking) has precluded the development of complete standardized operating procedures, resulting in a difficult performance measurement task. The developed technique is based on the use of submarine system effectiveness models (e.g., weapon systems effectiveness models). The model would generate complex measures of overall system or subsystem effectiveness which could be related to specific trainee actions. Although the operational forces were still using the analog-based fire control systems at that time, tactical operations were beginning to undergo substantial changes, which would be conducive to the use of this performance measurement approach (e.g., use of sound wave ray path analysis during approach and use of probability of counterdetection). These tactical changes coincided with the major new developments in sensors and fire control systems, such as the MK 81 weapon control console. These factors have led over the succeeding years to acceptance of the training concepts and capabilities that were to be embodied in SMARTTS.

The Naval Training Equipment Center took another step in the development of submarine tactics training capabilities by evaluating a laboratory version of the advanced training technology subsystem[10,11] that embodied many of the recommended training assistance capabilities. A variety of Naval training and operations personnel from Submarine Forces, Pacific (SUBPAC); Submarine Training, Pacific (SUBTRAPAC); Submarine Forces, Atlantic (SUBLANT); SUBSCOL; and other groups reviewed the capabilities of the laboratory version and participated in experiments with it. The response was uniformly strong in approval of using the advanced training technology concepts.

Additional support for the advanced training technology concepts came from naval training personnel at the 21A40 SCST site. The limited training technology concepts incorporated into the development of the handbook for the 21A40 SCST resulted in requests by the staff for the upgrading of their trainer to include several of these capabilities. The Naval Personnel Research and Development Center (NPRDC) developed a limited experimental capability on the 21A40 for investigating the effectiveness and acceptance of several of the recommended training assistance technology capabilities. Results from the investigation by Callan, Kelly, and Nicotra[12] of the operational training of submarine crews, showed increased training effectiveness as a result of the advanced training technology. Many of these concepts have been further incorporated into other training programs and devices (e.g., Sonar Operational Training and Assessment Program — SOTAP); these applications generally support the effectiveness of the advanced training technology concepts.

The advanced training technology concepts forming the training subsystem that should be integrated into the training device/simulator design were developed by a series of NTDC/NTEC investigations. The systematic applied development of the advanced training technology subsystem, however, remains to be undertaken. This is being accomplished via the SMARTTS program.

## TACTICS TRAINING SYSTEM

The training system, in any area of application, is composed of several elements. Various specifications for these elements are available[13,14]. A somewhat simplified version of the training system, as shown in Figure 1, consists of four major elements. The training objectives, which comprise the first element, specifically define the goals for which the remainder of the training system should be designed in the most cost-effective manner. The training objectives are typically the result of an analysis of tasks, skills, knowledge, performance standards, and conditions under which the preceding should be attained.

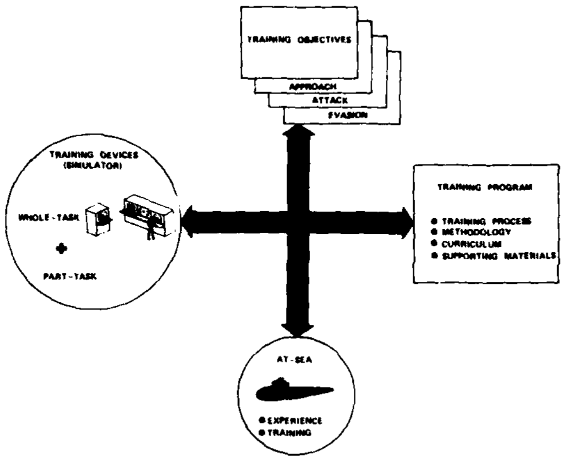


Figure 1. Elements of the Training System

The design characteristics for the remaining three elements of the training system should be determined on the basis of a trade-off analysis between each, so as to achieve the most cost-effective overall system design. The training program addresses the content of the training process as well as the methodology by which it is achieved. The materials to support the training process (e.g., instructor's guide, trainee handbook, and exercises) contain the training program. The training devices are tools to be used by the instructor as an aid in accomplishing the training objectives during the training program. The training system may have one or more training devices, including both part task and whole task trainers. On-the-job training, the final element represented in Figure 1, is an alternative to the training device in achieving certain of the training objectives. It is important that on-the-job training be investigated as a cost/effective means in trade-off with the training device.

Close integration between the design characteristics of the training device and training program is of primary importance to the achievement of a cost-effective training system design. The training device should be viewed as an aid to the conduct of the training program, in the achievement of the training objectives. To this end, the characteristics of the training device should be designed so as to aid the training program. This point is crucial; the training device should contain only those characteristics that most cost-effectively aid the training process. The modern training device, therefore, in the context of complex operational systems such as the submarine combat system, should have two major functions: 1) simulation of the operating environment and 2) training assistance (see Figure 2). The vast majority of simulator-based training devices in use today, by the military as well as commercial industry, do not adequately address the training problem. That is, they typically provide adequate simulation but provide little if any assistance to the conduct of the training process. The typical complex simulator/training device is computer based and has the capability to generate a wide variety of information relevant to the conduct of the training process, as well as provide much needed

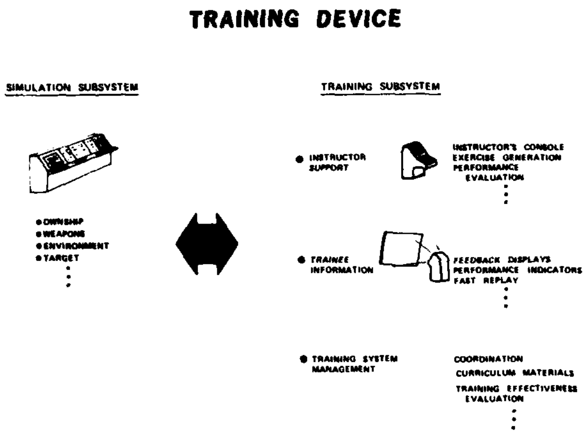


Figure 2. Major Subsystems of the Training Device and Their Functions

assistance to the instructor. This aspect of the training device has been grossly overlooked, although the basic capabilities may be readily developed to provide effective assistance to the trainees and instructor. SMARTTS directly addresses the training functions of the training device; it does not address the simulation function. SMARTTS keys on the training system concept, allocating to the instructor and other elements of the system those tasks for which they are most capable. For example, SMARTTS relieves the instructor from rudimentary tasks such as data recording, allowing him additional capacity to focus on more important tasks of the training process (e.g., monitoring trainee performance). Furthermore, SMARTTS capabilities supplement the instructor by generating needed information and providing control assistance which are typically beyond the capability of most instructors. Furthermore, the capabilities are designed to permit the evolution of the training system so as to be responsive to the constantly evolving operational and training needs. SMARTTS is a set of capabilities that represents the training function of the training device, in support of the training process.

## SMARTTS DESCRIPTION

SMARTTS will be the first major subsystem of a simulator-based training device developed specifically to support the training function, rather than the simulation function of the training device. An extensive requirements analysis, therefore, was necessary. This analysis drew heavily from previous investigations to define the tasks of the various members of the fire control and sonar parties on the SSN and SSBN. The available information was updated as necessary to address the tasks to be performed in support of the MK 117 and MK 113 Mod 9 fire control systems, and the AN/BQQ-5 and AN/BQQ-2 sonar systems, and the utilization of recently developed weapon systems. The analysis also identified skill and knowledge requirements as well as performance criteria, measures, and standards, and identified the comprehensive set of training objectives across submarine tactics training. The functional characteristics for the SMARTTS were developed in consonance with these. Additionally, hardware and software design aspects of the potential SMARTTS were analyzed during this analysis so as to delineate the potential costs of SMARTTS. The in-depth requirements analysis was necessary for SMARTTS since it represents the initial attempt to comprehensively define the training function of the training device. This represents a substantial change in philosophy regarding the design of the training device; that is, a change from simulator design to simulator plus training technology design. It, furthermore, represents the evolution of the training device from merely a support aid into a central integrating function directly impacting the design and conduct of many aspects of the training process.

SMARTTS provides the foundation upon which the integration of advanced training technology into the training device will have been developed and evaluated. Results of the test and evaluation phase of SMARTTS, in the operational environment, will complete the initial development. It will result in a catalog of demonstrated training technology concepts that can be integrated into other training devices in a wide range of applications. Subsequent applications of this training technology will require a considerably less extensive training requirements analysis since the concepts are generic in nature and may be readily tailored to many training applications. Rather, the development of a new training device would require an analysis only to identify the training objectives and to select from those SMARTTS characteristics that have already been developed. The selected characteristics would have to be tailored to the particular training application; this, however, would require considerably less effort.

SMARTTS will provide features to support three major aspects of the training process (see Figure 3): 1) trainee information, 2) instructor support, and 3) training system management. SMARTTS capabilities in each of these areas are summarized below.

### Trainee Information

The importance of feedback information to the trainee regarding the outcome of his actions has been known for many years as an essential part of an effective training process. Relatively little in-

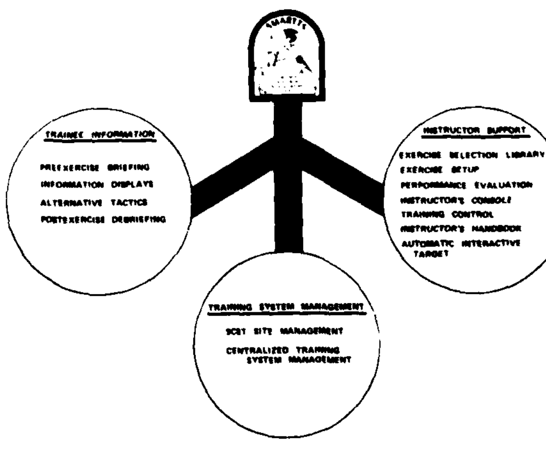


Figure 3. Major Support Areas of SMARTTS

formation is currently provided to the trainees prior to, during, or even after the training exercise on the SCST. The information that is provided to the trainee is generally a result of the instructor's observations, and is provided verbally immediately following the exercise. SMARTTS will provide capabilities to generate, store, and present performance-related information to the trainees. A wide variety of tactical and performance-related parameters will be computed during the exercise; these may also be computed prior to and following each exercise so as to discuss related points and alternative ownship actions. The generated parameters will be presented to the trainee on appropriately designed information displays (e.g., graphical, tabular summaries). SMARTTS will also provide the instructor with the capabilities to present the information in a variety of formats, tailored to the specific training problem. The information may be presented to the trainees on CRT monitors in the attack center (e.g., during a problem freeze) and on large screen displays in an adjoining classroom (i.e., prior to and/or following the simulator exercise). An example of a graphical display presenting several tactical performance indicators simultaneously is presented in Figure 4. The important aspect of these characteristics is that SMARTTS will provide the capability to generate and present the information. The particular performance indicators used, display formats, exercises, etc., will be tailored to the particular training problem; these are likely to evolve over time, changing to meet the changing training problem. SMARTTS will provide meaningful visual feedback to the trainee, enabling him to correlate his actions with relevant tactical parameters pertaining to his teammates, ownship disposition, and the target disposition. These characteristics represent the major area of SMARTTS concern. A summary of the specific characteristics follows:

- Preexercise briefing. A variety of capabilities will be available in a classroom context to assist the instructor in briefing the trainees prior to participating in the simulator-based exercises. The alternative tactics capability will enable fast-time generation of problems in the classroom, including the generation and display of performance indicators and other tactical parameters for a variety of ownship and target tactical actions. The classroom preexercise briefing sessions can be conducted while a different group is simultaneously participating in training on the simulator.

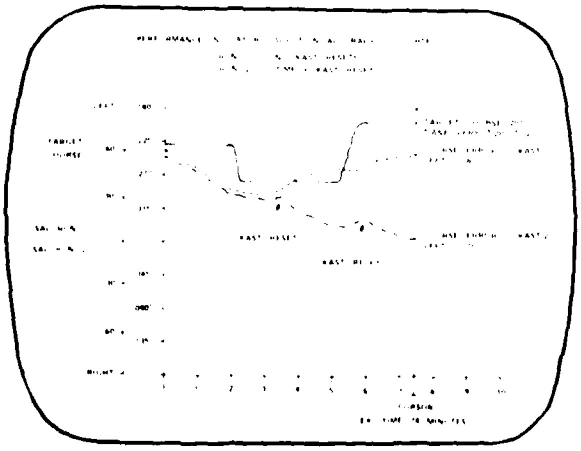

Figure 4. Example of Trainee Single Graph Feedback Display

- Information displays. SMARTTS will generate a variety of performance indicators and relevant tactical parameters (e.g., probability of counterdetection). The information generated can be presented to the trainees on CRTs in the attack center and on a large screen display in the adjoining classroom. These displays will provide the means to present information for the preexercise briefing discussions, immediate feedback during the simulator exercise, and the postexercise debriefing discussions. The information so presented will enable the trainee to learn and understand the relationships between the various tactical parameters of interest as well as the impact of his actions and ownship's actions on the tactical problem. The displays will be under control of the instructor. A trainee entry device (i.e., a button) will be available at each operating station to permit flagging of tactical events during the exercise for later discussion.

- Alternative tactics. Alternative sets of ownship and target actions can be generated in fast-time during briefings to enable investigation of the relationships between relevant parameters (e.g., the impact of earlier ownship maneuvers; the impact of different ownship maneuvers on target motion analysis quality). These will assist training by enabling direct comparisons of performance indicators generated during the alternative actions.

- Postexercise debriefing. The postexercise debriefing is currently used in SCST training. The SMARTTS information generation, storage, and presentation capabilities will greatly enhance this process. Postexercise debriefing will be possible in the attack center using the SMARTTS CRT displays. Ideally, however, the debriefing sessions will be conducted in the classroom using the large screen display. The SMARTTS capabilities will enable the presentation of all relevant information concerning the just-completed exercise as well as the generation and investigation of alternative sets of tactics for the exercise situation and other situations. The capability will be present for the instructor and trainees to completely analyze the tactical problem, and focus on aspects of particular interest.

Instructor Support

SMARTTS will greatly augment the currently limited instructor support facilities at each of the SCSTs. It will provide the instructor with additional capabilities to design and set up exercises, to control and monitor exercises while they are being conducted, and to provide more effective information to the trainees prior to, during, and after each simulator exercise. Instructor support capabilities are summarized below:

- Exercise selection library. A library of highly structured prestored exercises will be available for selection by the instructor. Each exercise will be keyed to tactical and training objectives. The exercises will be highly structured allowing for necessary modification by the instructor either prior to or during their conduct on the simulator. Furthermore, the set of available exercises will be standardized across all SCST sites.

- Exercise setup. An off-line capability will be provided to enable the instructor to develop and evaluate exercises prior to their use in training. A remote terminal will be provided for this capability. The instructor will be able to develop the exercises, run them in fast-time, and investigate the results. He can designate appropriate performance indicators, training objectives, event cues, and so on, which will be prestored with the exercise. Furthermore, this capability will enable him to compare different exercises and readily modify them to achieve particular exercise design goals. Finally, the instructor will be able to add the new or modified exercise to the exercise library for permanent storage.

- Performance evaluation. A set of performance indicators will be available under SMARTTS. A subset of these indicators will be keyed to each exercise, achieving automatic generation and storage of the performance data during the exercise. The instructor may develop and store additional performance indicators as well as modify existing performance indicators. Furthermore, he can designate additional performance indicators for a particular exercise or remove existing performance indicators from an exercise. Cues will be provided, keyed to each exercise, to alert the instructor to particular predetermined observation requirements. The variety of performance indicators, and other tactical parameters will be available at an instructor's remote console for monitoring during the exercise. The information will be presented on a CRT display in an appropriate format (i.e., graphical, tabular, or some combination); additionally, selected parameters will be available for monitoring on an instructor's portable handheld remote console.

- Instructor's consoles. A remote semiportable console will be available for monitoring and control of the trainee exercise. It will consist of a CRT display, general purpose keyboard, and function keyboard. This semiportable device will be easily moveable to different locations in the attack center. It will enable the instructor to monitor and control from an attack center location while observing the trainees. A portable handheld display will also be available to enable the instructor to monitor selected parameters while moving about in the attack center. Ideally, this portable display will be wireless. The instructor displays will present information related to the performance indicators, current tactical parameters, geographic track history, ownship status, training cues, instructional alerts, and alarm conditions.

- Training control. The instructor will have expanded capabilities to control the training exercise. These will include a freeze capability, projection of multiple ownship and target actions to evaluate their likely impact on the exercise, and analysis of trainee progress to assist in tailoring exercise selection and configuration.

- Instructors' handbook. A comprehensive instructor's handbook will be developed to assist in the development and conduct of an effective training process using the SMARTTS capabilities. The handbook will address the particular capabilities of SMARTTS as well as effective training practices. An instructor's course will be developed and administered to all instructors prior to their use of the SMARTTS system.

- Automatic interactive target. Currently, target actions on an SCST are either predetermined and canned, or controlled by the instructor. Target control by the instructor requires a considerable amount of time and often reflects the particular instructor's experiences rather than a representative set of target actions. The automatic interactive target (AIT) will provide for computer control of target actions, emulating in a probabilistic manner likely actions of the target, based on the best available intelligence information. The target will, in essence, react to ownship actions in concert with information provided via the environment, the target type, his mission, and the world situation.

Training System Management

The preceding two areas of SMARTTS primarily addressed conduct of the training process. The training system management capabilities of SMARTTS address the long-term structure and functioning of the training system and the training process. It provides for both intrasite and intersite management of the training process. Specific capabilities are as follows:

- Standardized curriculum materials. SMARTTS characteristics and other materials provided along with SMARTTS will be standardized across all SCST sites. These will include instructor and trainee handbooks, the exercise library, the SMARTTS system operator's manual, and an integrated curriculum across sites.

- SCST site management. The tactics training curriculum will be standardized across SCST sites, appropriate to the level of trainees and other factors being addressed at each site. Each site will participate in the development of the curriculum; each site will, furthermore, have the capability to tailor the curriculum to meet specific local needs. Changes in tactical doctrine would be quickly implemented by a centralized activity, resulting in a reduced administrative burden at each site. Instructor training will be standardized for SMARTTS across sites. Finally, various training methods will be recommended singly and in combination for use with various exercises; this will further standardize the training methodology employed across sites.

- Centralized tactics training system management. A training management structure has been identified to configure and control the training process across SCST sites. This structure would come under the force commander's direction and would provide more unified and controlled curriculum, procedures, and performance criteria. This structure would act as the coordinating body across all SCST sites. Furthermore, the effectiveness of training at each site, the effectiveness of the various training methods being employed, the exercises being used, etc., would be monitored by this central activity, providing for a long-term analysis of the system's training effectiveness and the training needs.

## SMARTTS DEVELOPMENT

The above discussion addresses the three major areas of SMARTTS, and summarizes characteristics of each area. These characteristics, which are explicitly identified in the SMARTTS Type "A" Specification,[15] pertain to the eventual production SMARTTS. A preprototype version of SMARTTS is currently being developed and installed on the 21A41 SCST at Norfolk, Virginia. This preprototype will incorporate the essential features of SMARTTS, although not all of the specific characteristics. It should be noted that the essence of SMARTTS is the general computer-based capabilities denoted by the three major areas; the specific characteristics under each of these areas are likely to evolve as SMARTTS is used, with changing operational problems, changing training needs, and developing training technology. The SMARTTS capabilities will enable this evolution of characteristics to occur.

The preprototype installation on the 21A41 SCST will enable the evaluation of SMARTTS in the operational training setting. Information is presently being collected at the 21A41 SCST and other SCST sites regarding the instructor functions, training methodologies employed, and tactical team performance prior to and following training sessions. These data collected from traditionally-trained groups will comprise the control group data base for comparison with the SMARTTS-trained groups after the preprototype installation becomes operational. The collection of SMARTTS training data, as well as the subsequent evaluation of the training effectiveness of SMARTTS, will be conducted by an independent group. The purpose of this investigation will be two-fold: 1) to evaluate the effectiveness of groups trained using the SMARTTS technology with traditionally trained groups, and 2) to evaluate and improve the training effectiveness of the various characteristics of SMARTTS. It is expected that although SMARTTS will prove to be a cost-effective adjunct to the simulator/training device, its relatively large number of characteristics will have differing degrees of training effectiveness. Furthermore, it is expected that these characteristics will be improved over time and will be supplemented by additional SMARTTS characteristics as appropriate to enhance the training process. It is the intent, therefore, that the SMARTTS evaluation also generate information relevant to the improvement/evolution of the various SMARTTS characteristics.

SMARTTS is a training subsystem specifically designed to meet requirements for the tactics training of submarine officers. The training technology concepts identified and developed, however, embody considerable generic aspects. Hence, they are likely to be directly applicable to most simulator-based training systems. It is likely that SMARTTS-type capabilities should be resident on many major computer controlled training devices. Specific characteristics, such as particular performance indicators and display formats, necessarily have to be tailored to each particular training application. Nevertheless, the generic capabilities represented by SMARTTS are potentially applicable to substantially impact the effectiveness in a wide range of training areas. For example, the SMARTTS technology has been applied and investigated for application in commercial deck officer training on ship bridge/shiphandling simulators; preliminary results indicate that this type of technology would substantially impact the effectiveness of those training devices. As an order of magnitude estimate, the SMARTTS capabilities, if developed and designed into the training device when initially procured, would cost about 20 percent of the device cost. Since the characteristics are predominantly implemented in software, relatively minor additional cost increments would be required for additional production units.

The training device, albeit a simulator, has often been developed independently of the other elements in the training system. The potentially extensive training assistance capabilities of the training device/simulator when configured to provide the SMARTTS-type training technology, necessitate close integration with the other elements of the training system so as to achieve the most effective design. Whereas the training systems design approach (e.g., Instructional Systems Development approach has often been ignored in the past, the potential training effectiveness gains to be achieved by incorporating the SMARTTS-type technology make the systems approach mandatory. The training device should not be independently developed; rather, it must be developed and closely integrated with the training program to meet the specific training objectives.

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# AN ALL-SOFTWARE IMPLEMENTATION OF EMBEDDED TRAINER CAPABILITY

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## ABSTRACT

For certain weapons systems, an all-software implementation of the operator proficiency trainer is possible. The prospective benefit is reduction of unit production costs. Suitable systems for this approach are generally identifiable by their use of computer display and control consoles as operator stations. The system's basic equipment configuration may appear to impose limitations for training usage, such as lack of an instructor station or a computer memory with insufficient capacity for storing the data of a realistic simulation scenario, but in a cost-effectiveness appraisal of the all-software approach, the possibilities for software solutions to these hardware limitations should be considered. This paper reviews these considerations and the design decisions for a specific case, the Troop Proficiency Trainer of the U.S. Army's PATRIOT Air Defense System. In this trainer, simulation driver software is combined with tactical computer programs to produce highly realistic training exercises, and considerable flexibility is achieved for scenario selection and other aspects of exercise control.

## WEAPONS SYSTEM OPERATION

PATRIOT is a guided missile system designed to counter the threat to field army air defense through the 1980's and 1990's. The threat is characterized by defense suppression tactics of maneuver, electronic countermeasures and numerical saturation. One of the key features in the PATRIOT response to this threat is automated operation with provisions for human override.[1]

The Engagement Control Station (ECS) is the center of operational control in the PATRIOT Fire Unit (Figure 1) and is the only manned station in the Fire Unit during battle. It houses operators, a weapon control computer, man-machine interface and various data and communications terminals. Operational control at the ECS involves radar surveillance, target evaluation, launch decision, weapon assignment, missile guidance, Fire Unit status monitoring and communications.

Another unit which is manned during battle is the PATRIOT Command and Coordination Set (CCS). The CCS (Figure 2) is the operational control center for coordinating PATRIOT firepower with other users of the airspace. It interfaces with U.S. Army air defense group facilities, neighboring CCSs and with several ECSs. It houses operators, a weapon control computer, man/machine interface, and various data and communications terminals. The primary physical difference between the CCS and the ECS is the absence of radar interface and launcher communications equipment in the CCS.

In both the ECS and CCS, human override of automated operations is facilitated by a man-machine interface consisting of displays and controls hardware (Figure 3) and associated software. The displays and controls design includes two operator consoles: console mode selections enable the division of operator tasks. System status information is displayed in tabular format and on indicator panels. Cathode-ray tubes display the air defense situation, related tabular data, and alert messages. The operators monitor system operation via these displays and enter override commands and data via console switches and keys. Clearly, these operators require continuing practice in realistic training exercises in order to maintain and enhance their proficiency and readiness.

## EMBEDDED TRAINER REQUIREMENTS

Refresh training is a requirement for PATRIOT system operators. It prescribes a capability to simulate enemy air attacks on assets defended by the system, with modeling of the effects of maneuver, ECM, weather and other environmental influences, combined with a means for evaluating operator responses to such attacks. It further states that each prime item of equipment (ECS and CCS) shall incorporate this training capability and be self sufficient for maintaining operator proficiency. The training requirement also implies an ability to train without emitting radiations, either radar or radio. The major safety requirement is to prevent inadvertent missile launch.

## ALL-SOFTWARE DECISION

In design studies performed prior to implementation, several factors influenced the hardware/software allocation of trainer functions. One constraint was available space; there was virtually no place left in the ECS and CCS shelter for installing additional equipment. However, considerable hardware capability was already present in existing displays and controls (Figure 3) and the tactical computer configuration (Figure 4). The alternative of using the tactical configuration of computer and displays appeared highly consistent with the need for realism in training exercises. The fact that computer-synthesized data is displayed (target symbols vice radar return analog representations, etc.) meant that display images of realistic quality could be generated by the computer, without the use of stimulation equipment. With two operator consoles, instructor participation in training exercises was possible. With magnetic tape for off-line storage of programs and scenarios, complete isolation of the trainer from tactical software was possible.

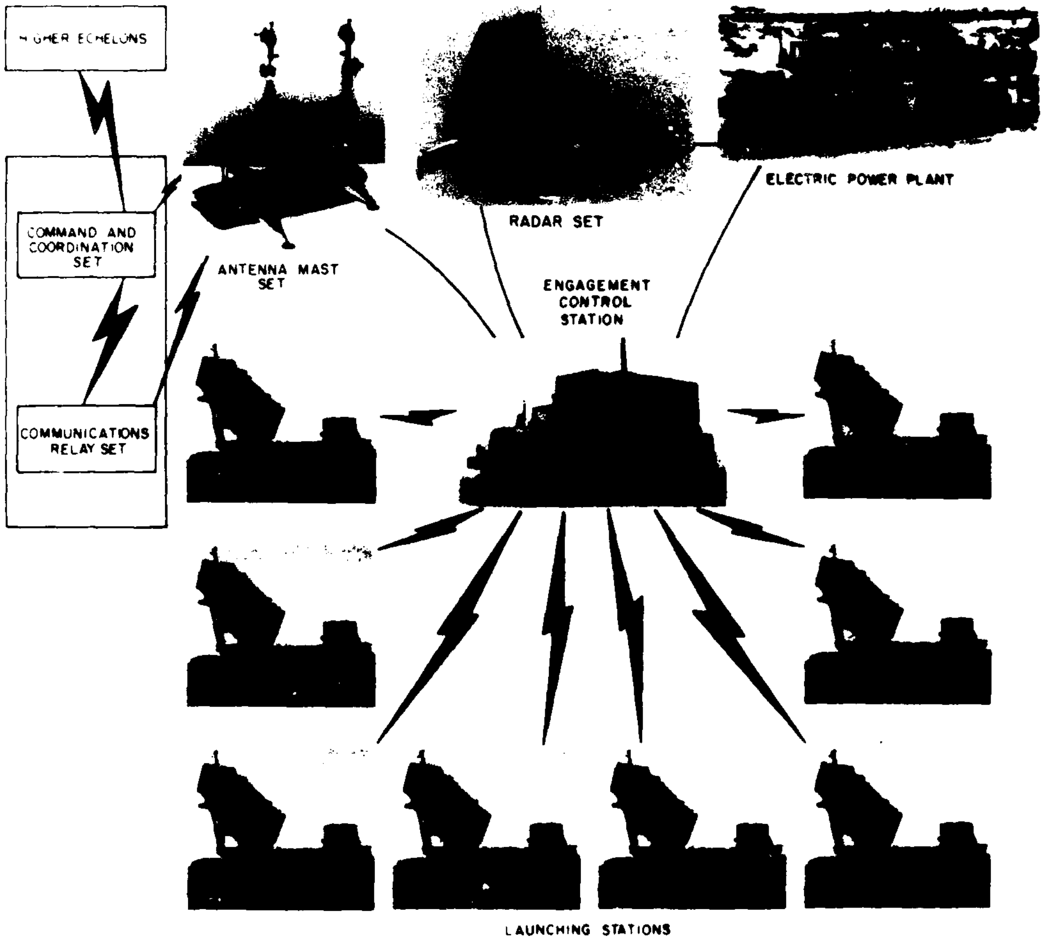


Figure 1 - PATRIOT Fire Unit

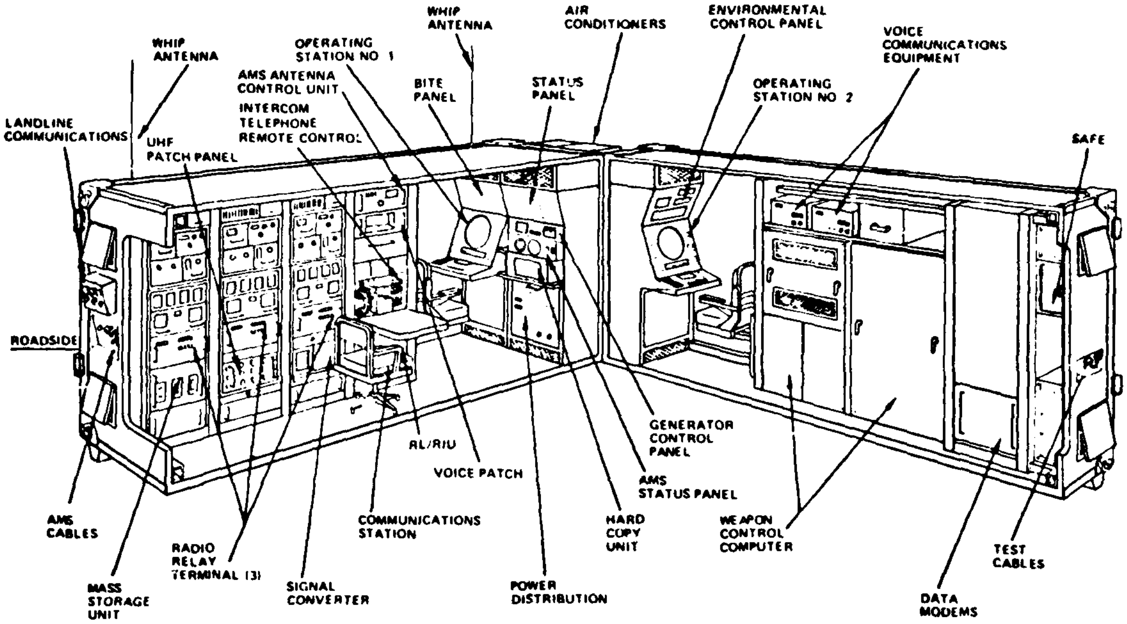


Figure 2 - Cutaway View, Command and Coordination Set

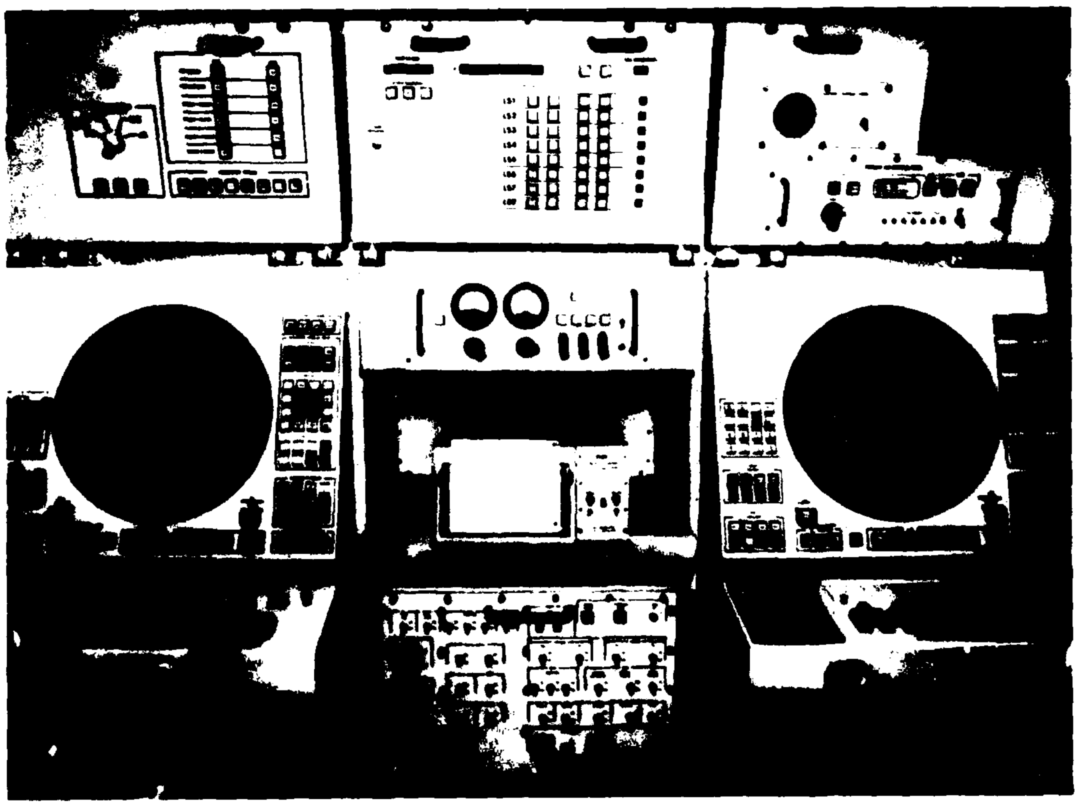

Figure 3 - Forward End of ECS Shelter Interior

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PROCEEDINGS OF THE 2ND INTERSERVICE/INDUSTRY TRAINING EQUIPMENT--ETC(U)
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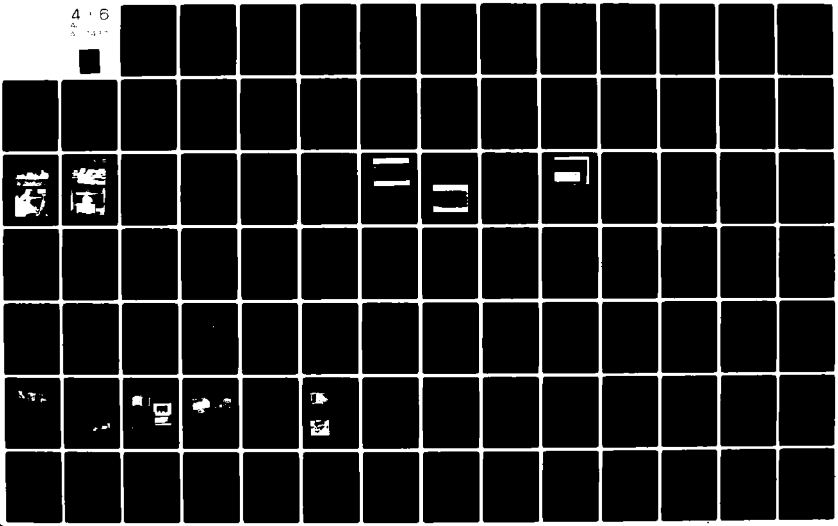

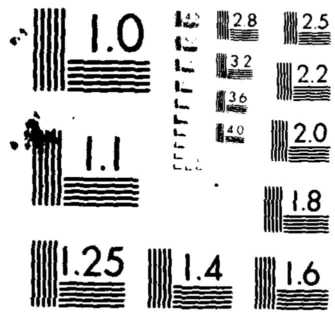


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

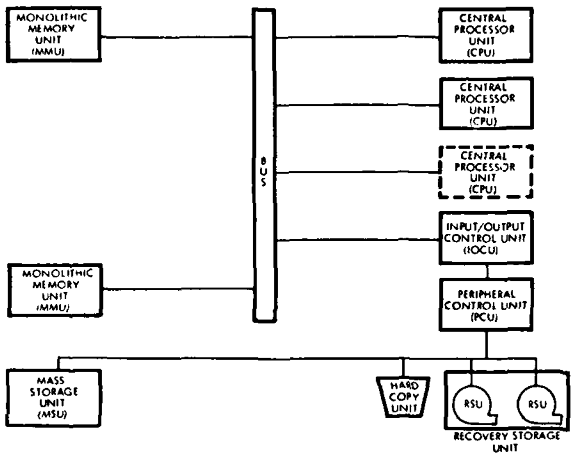


Figure 4 - Weapon Control Computer and Peripherals

In what is believed to be the first such instance among army air defense systems, the decision was made to implement an embedded refresh trainer capability entirely in software for existing tactical hardware. The result is the PATRIOT Troop Proficiency Trainer (TPT).

## PATRIOT TPT DESIGN

In overview, the PATRIOT Troop Proficiency Trainer involves both off-line and on-line data processing (Figure 5). Data preparation, the function of TPT off-line data processing, is performed with the aid of three software subsystems including the TPT Preprocessor. On-line trainer utilization, employing the existing tactical hardware of an ECS or CCS, requires one of two software subsystems, the ECS or CCS TPT.

### Preprocessor

The TPT Preprocessor makes real-time simulation exercises possible in the ECS TPT and CCS TPT by reducing the on-line processing load and the on-line computer memory requirements. The Preprocessor reads input script statements which control data base maintenance, scenario generation, and output functions. The data bases created and maintained by the software contain flight profiles (a maximum of 50 per profile data base); performance characteristics by aircraft or missile type (a maximum of 64 types per characteristics data base); locations of ECS and CCS sites, with Fire Unit radar oreintations; geographic coordinates of all locations of interest (a maximum of 400 locations per location identifier data base); and a model of local terrain elevations, (with a maximum 1980 points). These data base capacities are parameter values based on host computer (1108) memory limitations. These data bases are referenced during scenario generation. As many as 180 data bases (any mix) may be stored on one tape.

Scenarios produced by the Preprocessor consist mainly of flight paths. These are scripted by a choice of several methods, including point to point, speed/heading, profile, and related flights. Other scripted events include communications messages; jamming events; track breaks due to environmental effects; and damage to defended assets. A flight path is forced into terrain following at a specified height above ground level if it is scripted to fly below that height (take-offs, landings and impacts excepted). The terrain model is also used by the Preprocessor for determining occultation or masking of flights in ECS TPT scenarios. Geometrical processing of a scenario eliminates data beyond the sector bounds of the specific ECS or CCS site and converts coordinates to that sector's coordinate system. Scenario preprocessing also includes position/velocity calculation along flight paths at fixed-interval time steps, and the time ordering of all scenario data. The output function of the TPT Preprocessor produces error listings, data base listings, data base tapes, scenario listings and scenario tapes. The Preprocessor runs on a UNIVAC 1108 computer system, a choice based on the availability of an existing Preprocessor that was modified for TPT.

### Other Off-Line Functions

Scenarios are transferred from nontactical tape to tactical peripheral tape by a PATRIOT utility routine that runs on a special system.

Data base tapes for TPT exercises may be prepared in the field and, accordingly, this process may be considered part of the training exercise even though tactical software, rather than TPT software, is involved. The data base produced, including any errors, is input to the TPT exercise and subsequently recorded in the evaluation data output of the ECS or CCS TPT.

### On-Line Software

The software of the ECS TPT or CCS TPT operates in three phases: Initialization, Operator Exercise, and Evaluation (Figure 6).

### Initialization Phase

During initialization, TPT software is loaded into the WCC from tape, then a data-entry type of tabular display is presented at the operator consoles. Guided by its format the Training Officer keys in exercise identifying data (operator crew, site ID and date: scenario identification is automatically recorded) followed by exercise control parameter values. These specify the subset of assets to be defended; kill efficiency (a factor contributing to probability of kill in the kill determination algorithm); scenario duration (full, or an early stop time); the subset of scenario flight paths (range of numbers and odd/even selection); and ECM permit/suppress. All of these parameters affect the difficulty of the training exercise and they facilitate exercise problem variations with a single scenario. The Training Officer next sets the initial simulated missile inventory, which will be decremented during the exercise. Map displays from the data base are available to him at this point in the sequence, and panel indicators display status data, as aids in briefing the operator crew for the training exercise.

### Operator Exercise Phase

Operator exercise software is driven by a simulation control function which processes data

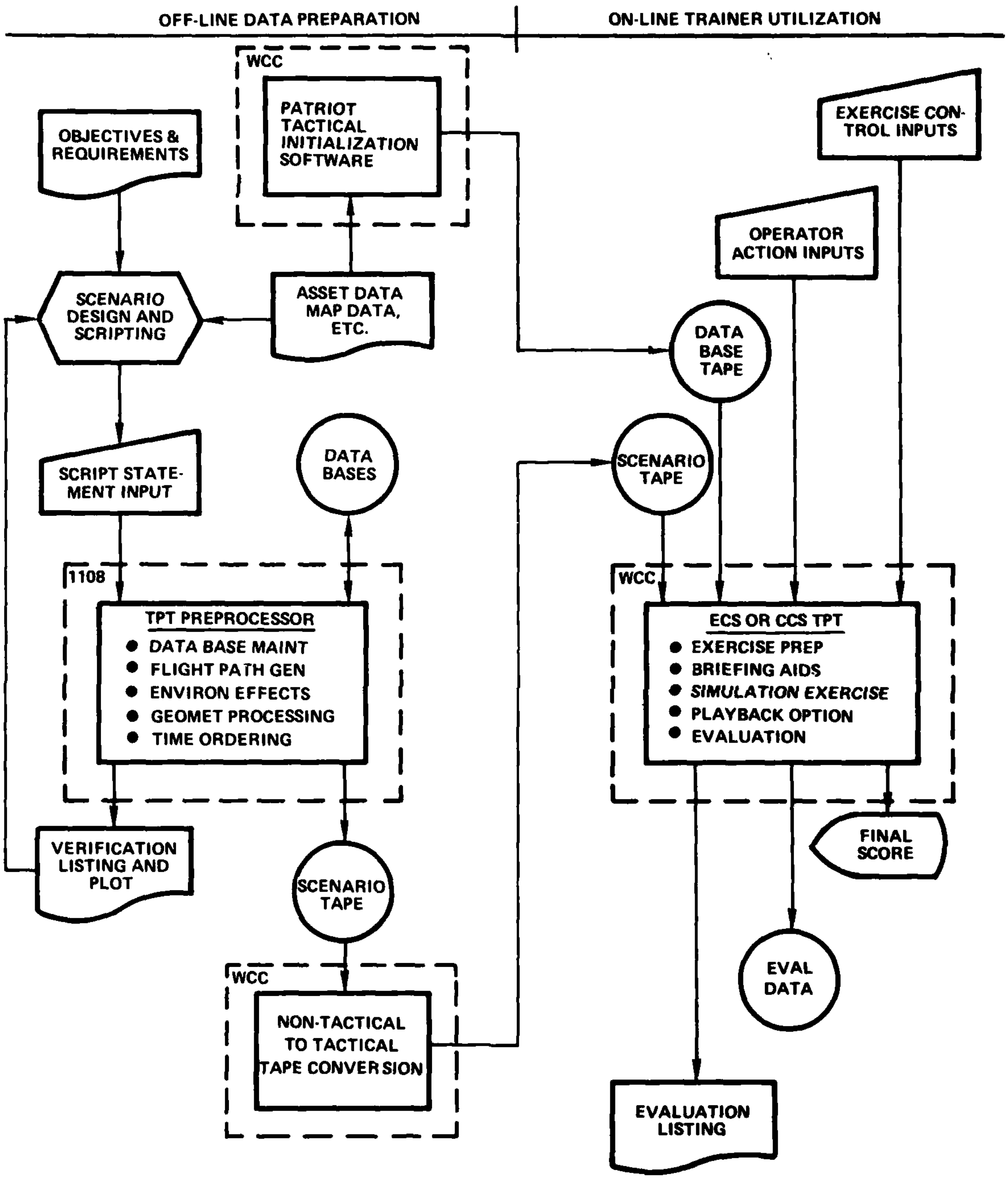


Figure 5 - PATRIOT TPT Data Processing Overview

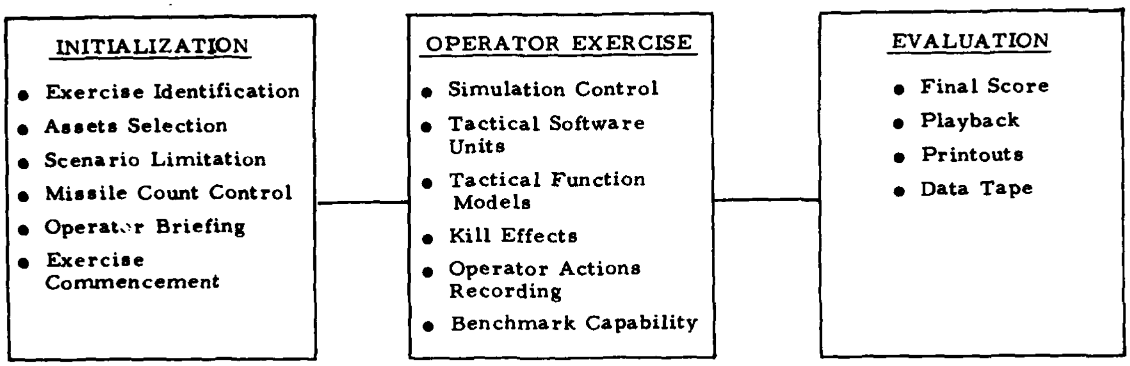


Figure 6 - ECS and CCS TPT Processing Phases

from the scenario tape in time order. Some of the tactical software program units, particularly those which service the displays and controls, are incorporated in TPT for the assurance of realistic system response. The remaining tactical software functions are modified by the TPT software, retaining essential aspects and supporting the simulation. This use of simplified models of selected tactical software functions bypasses actual radiation; controls input variables; and has the desirable side-effect of making WCC memory space available for additional TPT software functions. Reactivity of the simulation is limited to kill effects: if the software assesses a kill then the flight formation size is decremented by one, and subsequently all related displays, communications messages, decoy launches, air-to-surface missile launches, and asset damage events are inhibited accordingly. In the event that the last missile is expended and it completes its flight, or upon 100 percent damage to the defending CCS or ECS, the operator exercise terminates prematurely and the remainder of the scenario advances at an accelerated rate with only the damage events being processed. Otherwise the exercise terminates at its scheduled completion. During the exercise the software saves all operator inputs, including time of occurrence, switch or key action, and the operator console identifier. These are used during the evaluation phase. An exercise may be conducted with no operator inputs, resulting in a fully-automatic benchmark run which provides the Training Officer with one standard against which to evaluate operator performance.

Evaluation Phase

Immediately following the exercise (i.e., at early stop time or upon scenario completion, whichever was selected during the initialization phase) a final score is computed and displayed. Ranging in value from 0 to 100, this score measures the survival of defended assets. Its formula is

$$\text{FINAL SCORE} = \left(\sum_{a=1}^{N} (100-D_a)(W_a)\right) / \sum_{a=1}^{N} W_a,$$

where

a is one of the N assets selected during initialization,

D is limited to a maximum value of 100 and is the cumulative percentage of damage assessed against an asset during the operator exercise phase, and

W, a weighting factor, is the asset's value which is obtained from the tactical software data base.

For the final score to be less than 100, there must exist scripted damage events in the scenario, and the damage-perpetrating flights must successfully pass several filters, including the geographic sector selection of flight paths performed by the preprocessor; exercise duration and simulation reference number (SRN) subset selection performed during initialization; and kill determinations resulting from engagements during the exercise. Scripted for each damage event are time of occurrence, SRN of the perpetrating flight, identification of asset to be damaged, and a damage percentage increment. If the flight remains in the exercise at the time of occurrence, then the increment is multiplied by the number of vehicles remaining in the flight, and the product is added to the cumulative percentage of damage (D) for the asset identified. By killing flights that threaten defended assets before damage occurs, the operator team improves its final score.

Playback of the entire exercise is one selection available during the evaluation phase. The software accomplishes playback by resetting the random number seed for kill determination; playing the scenario tape over again; injecting saved operator actions at the times indicated; and ignoring real operator inputs.

Other selections that may be made at the operator consoles during the evaluating phase are data recording on tape (including identifying data; exercise control parameters; data base; and the record of operator actions), and printouts of three different lengths, containing some or all of the data that is recorded on tape.

These evaluation aids, the final score, the printout of data, and the playback capability, are intended for the use of a Training Officer in evaluating performance relative to factors such as friendly aircraft protection and number of missiles expended, as well as the asset survival factor.

## IMPLEMENTATION EXPERIENCE DATA

The TPT development phase, including software requirements definition through integration and operational testing, was completed in January, 1980. Production of additional TPT units involves only the copying of software and documents.

TPT and PATRIOT tactical software were developed simultaneously, with selected tactical program units transferred and integrated into TPT (Figure 7). Simultaneous development and the integration of untested tactical program units complicated TPT debugging. However, the availability of TPT provided an unexpected benefit when it was discovered that TPT was an excellent simulation test bed for checking out and debugging tactical programs for target evaluation, launch decision and weapon assignment. The use of selected tactical program units in TPT reduced development cost, enhanced the realism of system response, and is expected to simplify the updating of TPT when the associated tactical functions change.

The combined size of the TPT software, including Preprocessor, ECS and CCS TPT, but excluding integrated tactical program units, is approximately 32 thousand lines of source code.

## DISCUSSION

The PATRIOT Troop Proficiency Trainer may be characterized by several previously mentioned attributes, including:

- Software implementation
- Use of existing equipment
- Absence of remote instructor console
- Negligible unit production costs
- Real-time simulation
- Large-scale, realistic simulation
- Limited reactivity (kill effects only)
- Ease of updating

Performance-related design decisions were concerned mainly with the unloading of on-line scenario processing functions to off-line preprocessing in order to assure a real-time simulation update rate. The results are a scenario capacity of approximately 2000 target minutes (average track load times scenario duration), realistic target maneuvers and environmental effects, capacities for number of multiple simultaneous engagements and number of targets simultaneously tracked equalling those of the PATRIOT tactical system, all at a real-time simulation rate. The previously described limitation of simulation reactivity to the area of kill effects does not represent a permanent constraint; additional reactivity is possible through software modification.

TPT training exercises are repeatable. Some variations are possible through exercise parameter selections during initialization, but control on this source of variation is established by recording parameter values in the TPT evaluation outputs. Control of variables is further extended by use of a prescripted scenario as the main source of data for the training exercise; limitation of on-line reactivity; and limitation of random-number usage to the kill determination algorithm. As a result, TPT training exercise results may be used in comparative evaluations (Skill Qualification Tests for example) and as the basis for statistical analysis.

A most significant advantage of software for trainer implementation is ease of accommodating training objective changes or other changes of a basic nature. For example, the Army's PATRIOT Project Manager, Maj. Gen. Oliver D. Street III recently wrote that new technology and system capabilities call for a review of current air-defense doctrine, which is damage-limiting and tends to concentrate on protecting critical assets.[2] This doctrine is reflected in TPT's final score, which rewards PATRIOT operators for minimizing damage to their defended assets. If air defense objectives were to change to area defense and zone-penetrating raid attrition, only four TPT software changes would be required: selection of a zone rather than assets during initialization, replacement of damage counting with penetration counting, change of the final score to a measurement of raid attrition, and replacement of TPT's integrated tactical program units that perform target evaluation with updated versions. This change in TPT's training objective would be accommodated simply by changing the software tap tape that loads the trainer into the tactical equipment.

| TACTICAL SOFTWARE | | TPT SOFTWARE |
|---|---|---|
| | | • Initialization<br>• Exercise Phase Control |
| • Real Time Executive<br>• Displays and Controls Information Processing<br>• Target Evaluation, Launch Decision and Weapon Assignment Logic | XFER → | • Real Time Executive<br>• Displays and Controls Information Processing<br>• Target Evaluation, Launch Decision and Weapon Assignment Logic |
| • Surveillance, Guidance, Communications and Status Monitor Functions | | • Models of Remaining Tactical Functions |
| | | • Evaluation Phase Control |

Figure 7 - Software Functions Correspondence, ECS Case

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2.) Street, MG O. D., III and LTC K. N. Brown, "Army Air Defense: A New Role?," Army, Vol. 30, No. 5, pp 24-29, May 1980.

## ABOUT THE AUTHOR

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# ADVANCED FIGHTER AVIONICS SIMULATION DESIGN: THE SIMULATE/STIMULATE QUESTION


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## ABSTRACT

In the real-time simulation of advanced fighter avionics systems, a critical design decision is the choice of stimulating the actual aircraft hardware subsystems or simulating the subsystem function via general purpose computer. This case study of a design decision addresses the effects on many aspects of the aircraft training or research device; training features/research capability, reliability and maintainability as well as major impact on the development/delivery schedule.


## INTRODUCTION

The Fire Control Computer (FCC) of the F-16 avionics suite is the primary processor and system data bus (multiplexed serial data) controller. The successful and timely integration of an F-16 avionics simulation is therefore keyed to this critical on-board computation/communication system.

Due to the high technical risk of the complex avionics simulation and schedule restraints, three major design approaches were pursued. The first was the utilization of the actual on-board Fire Control Computer system and the stimulation of this device by supplying all external inputs normally received in the aircraft. Another design pursued was the translation of the software program called the Operational Flight Program normally run in the Fire Control Computer from JOVIAL into FORTRAN, which could then be integrated with the flight simulation in the simulator general purpose computer. The third design approach which was followed to successful completion was to simulate the Fire Control Computer's functions based on the operational specifications and derived primarily from the equation derivation level of aircraft system documentation. This design selection represents a major departure from present industry practice. The reduced cost and improved training/research capability as well as significantly reduced implementation schedule indicate that the automatic acceptance of aircraft hardware engineers and manufacturers suggested techniques may be adversely affecting key high-technology design decisions in training/research simulation devices.

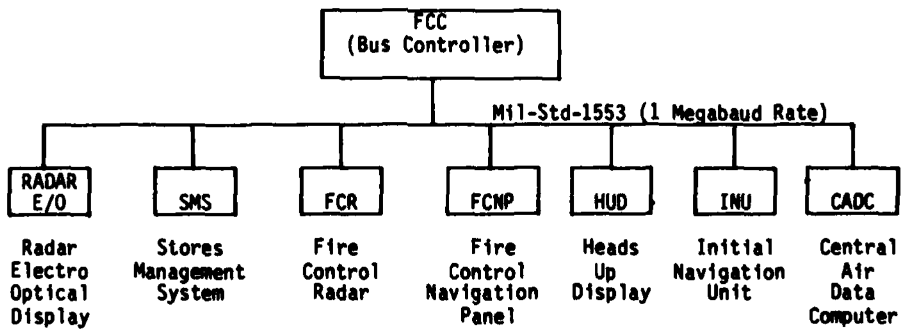
## BACKGROUND

### F-16 Simulator Program

The Advanced Simulator for Pilot Training (ASPT) F-16 simulation program was designed after the successful A-10 "phased" conversion of an existing T-37 cockpit. The F-16 phase I effort was comprised of minimum objectives directly comparable to those of the A-10 program (1), with a prioritized list of Phase I goals which markedly extended the simulator's capability.

The F-16 Avionics System was a critical high-risk component of the program. The goals for this system simulation consisted of a prioritized list (generated by Tactical Air Command) of training capabilities. This list consisted of specific navigation and air-to-ground (A/G) delivery modes via the Heads Up Display (HUD) as well as physical control panel functions such as the Stores Control Panel and Fire Control Navigation Panel. Priorities were based on projected training schedule and needs.

Research requirements included all of ASPT's conventional advanced training features. These include "Freeze", "Set", Reset", weapons release condition Capture and Recall, "Record", "Playback", and specially configured tactical conditions. Special features for avionics system




Aircraft Avionics Mux-bus Configuration

training were anticipated such as on "Freeze" target identification and target tracking information based on Heads Up Display (HUD) symbology. Other special control features were also anticipated, though not defined.

F-16 Avionics System

Although the primary design decision to be discussed is the Fire Control Computer (FCC) simulate versus stimulate question, some background of the aircraft avionics system is helpful for a basic understanding of the problem.

The F-16 avionics system consists of nine primary subsystems with a common high speed multiplexed serial data bus for digital communication. The Fire Control Computer (FCC) serves as the controller for all digital communications between subsystems and is also the primary controller and processor for most of the advanced avionics features available on the F-16. All air-to-ground and air-to-air ordinace delivery modes, except manual bombing and snapshoot gunnery mode, are implemented in the FCC. Heads Up Display (HUD) navigation is also supported by the FCC.

The Fire Control Computer (FCC) is a moderately high speed 16-bit digital mini-computer built by Delco. The Delco "Magic 362-F" (FCC) has 32K bytes of random access core memory and has floating point arithmetic instructions. The FCC interfaces with the rest of the avionics system primarily through its Mil-Std-1553 serial data interface, although it also has analog and discrete channels.

AVIONICS SYSTEM DESIGN ALTERNATIVES

Stimulate the Aircraft Hardware

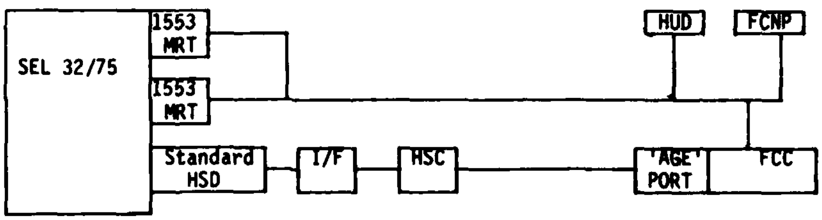
This approach strikes a warm spot in the hearts of pilots and aircraft hardware manufacturers alike. The key potential advantage with stimulating the F-16 FCC is that the on-board operational flight program (OFP) might be used without modification. This should result in excellent simulation fidelity as well as the capability to easily update to new software changes in the aircraft (block updates). This approach would also appear to minimize simulator software and hardware since the aircraft FCC will control the avionics system. These potential advantages had a number of implementation shortfalls.

Stimulation Implementation

The conventional "stimulate" approach was considered the lowest risk approach and was therefore a primary early effort. The hardware configuration to support this approach had already been defined by the Air Force Avionics Lab (AFAL) at Wright Patterson AFB as well as the in-development Singer F-16 simulator. Two key hardware interfaces are required to support this approach. A sophisticated device is required to allow the general purpose (GP) computers complex to act as multiple remote terminals (MRT) on the 1553 mux bus. This MRT device allows the GP computer to respond normally to the FCC as the Inertial Navigation Unit, Central Air Data Computer, Radar, or any other aircraft subsystems that are not present. For example, the Stores Management Subsystem was not available within the program schedule. The complexity of the MRT interface is due to the 1553 communications protocol, primarily the requirement for a subsystem to respond with valid status within five micro-seconds after a command transfer to that sub-system. Since GP computer software intervention is not possible within that time frame, high speed processing and memory is required within the interface. (There are also other stringent protocol requirements.) The MRT device may also serve as a bus "monitor" to capture key intra-subsystem data, or as the bus controller. This interface did not exist for the ASPT SEL 32/75 GP computers. The contract for this interface was let in the first months of the program. The final product was delivered about two years later, more than a year behind firm schedule commitment despite technical relaxation of specifications. This development had been considered medium risk, since the subcontractor had developed a similar device with less sophistication for several other computers.

The other primary interface required to support the FCC in a simulator system is an interface to the FCC's Automated Ground Equipment (AGE) port. This interface allows GP computer control such as halt and run, program loading, and rather slow speed indirect memory access to the FCC through a special set of FCC registers. The interface is an adaption of the High Speed Controller (HSC) interface of the production ground support mini-computer system. This interface was constructed and tested via contract within schedule. Outstanding support was provided by AFAL, which had previously constructed the device for another computer.

The hardware "stimulation" approach got more involved when the advanced training/research features had to be considered, since the FCC's software (OFP) was not designed for simulation. Scoring of weapons delivery, for example, is rather challenging. One method is to access the FCC memory locations for computed impact coordinates through the AGE port after detecting a weapon release command on the 1553 mux bus to




"Stimulation" Hardware System Diagram

the Stores Management System. A less involved method is to run a ballistics model in the GP Computer to score in parallel at weapon release time, again detected by bus data to SMS. The implementation of a "Freeze" function is also more than a trivial solution. One method is to utilize the bus monitor to store the command and data stream from the FCC. At "Freeze" time, the FCC is halted, the BCU interface is switched to bus controller mode, and the last list of stored data transfers is run continuously. An alternate method involves freezing the position and attitude data from the INU and accessing a few key integrating variables in the FCC through the AGE port. These problems were not solved on site as this approach was delayed more than a year and a half by subcontracted MRT interface schedule slipages. Microcode problems in supporting the complex multiple remote terminal capability in real time were a primary problem. The stimulation approach was finally dropped to provide the full support to the successful third approach as on-line capability was demonstrated.

Emulate the FCC (Translation)

This approach was based on the translation of the FCC software OFP from its source language, JOVIAL, into FORTRAN. The FORTRAN equivalent could then be compiled and executed in the basic flight simulator SEL 32/75 GP Computers. This high level language translation was required because a JOVIAL compiler was not available for the SEL 32 computer. The hardware configuration to support this approach is the same as that of the simulation approach; considerably simpler than the stimulation effort and offering direct control over the avionics system.

Translation Implementation

The major effort in this approach was the massive translation effort as well as the integration of this "foreign" software into the simulator system. This approach was supported through a partial translation effort. The effort was dropped due to the projected complexity of debugging and integrating the massive translated program. The complexity was due to the architecture of General Dynamics Operational Flight Program (OFP) which was constrained by severe memory and execution time limitations. The integration problem was again related to this OFP's "real-world" derivations versus the more real time efficient simulation models. Insufficient manpower, calendar time, and computer systems time for the translation, integration, and debug of this approach led to this approach's demise early in the program. The effort was greatly reduced, then dropped to provide full support to the simulation design approach as it demonstrated on-line capability. This approach should not be seriously considered unless the host GP Computer has a JOVIAL compiler or schedule and software manpower are not considerations.

Simulate the FCC

The objective of the FCC simulation approach was to minimize hardware and software complexity and allow early on-line operation with a prioritized growth of the simulation envelope. The complexity of the hardware configuration to support this approach is drastically reduced by assuming the FCC's role of 1553 bus controller. The configuration will be defined in the implementation section.

This design approach was to accurately model all FCC outputs to the hardware-pilot interface subsystems implemented in Phase I of the ASPT F-16 emulation, i.e., Heads Up Display and Fire Control Navigation Panel (FCNP). FCC internal computations and communications are eliminated wherever possible. This eliminates the requirement for an Inertial Navigation Unit (INU) math model and reduces the complexity of the Fire Control Radar (FCR) subsystem model.

No malfunctions or degraded modes are simulated except for total subsystem failures; i.e., FCC, CADC, INU fail. The FCC simulation approach is of course ideally suited to support the various avionics failure modes when research or training requirements for this enhancement are generated.

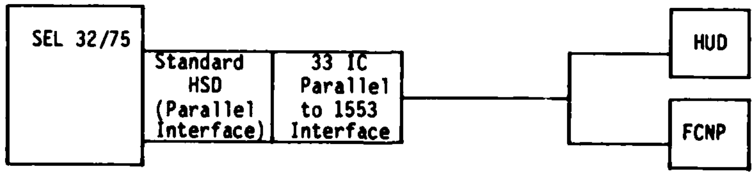
The functional simulation of the FCC, therefore, shall extend only to the man-machine interface. No attempt to model the internal architecture of the operational flight program (actual FCC software) was made due to the following reasons:

- Weapon delivery modes and navigation modes are not independent structural entities due to memory limitations. This is not consistent with the requirement for prioritized growth of capability which can be pursued as parallel development effort.
- OFP is generally not designed to integrate efficiently with the simulation flight model.
- OFP uses re-entrant routines extensively.
- OFP is cluttered with failure testing and degraded modes.

Simulation Implementation

Hardware

The GP computer interface problems were vastly reduced by assuming the FCC's role as bus controller. The MRT device sophistication was not required, and a simple parallel to serial 1553 interface (33 integrated circuits) was




Simulation Hardware system Diagram
(Same for Translation)

designed and built in-house. This device was mounted on a connector board to an off the shelf parallel interface (High Speed Data set - HSD) for the SEL 33/75 computer. All bus communications are under direct software control by the simulator GP computers. The AGE port interface was no longer required, since the FCC is not used.

The aircraft hardware subsystems used in the simulator (HUD, FCNP) receive all digital, discrete, and analog signals normally presented for any of the simulated operating modes at data rates greater than or equal to that supported by the aircraft. Communications with other simulated subsystems such as the SMS or FCR take place through memory shared within the same host computer. The SMS subsystem had to be simulated because a critical component of that system, the Central Interface Unit (CIU) was not available within schedule. The display of the SMS subsystem, the Stores Control Panel (SCP) was interfaced and supported by the SEL 32/75 GP computer system. The interface and extensive interactive software development was a considerable effort and offered no advantages over the use of the aircraft hardware.

Serial Data Transmission Rates (Hertz)

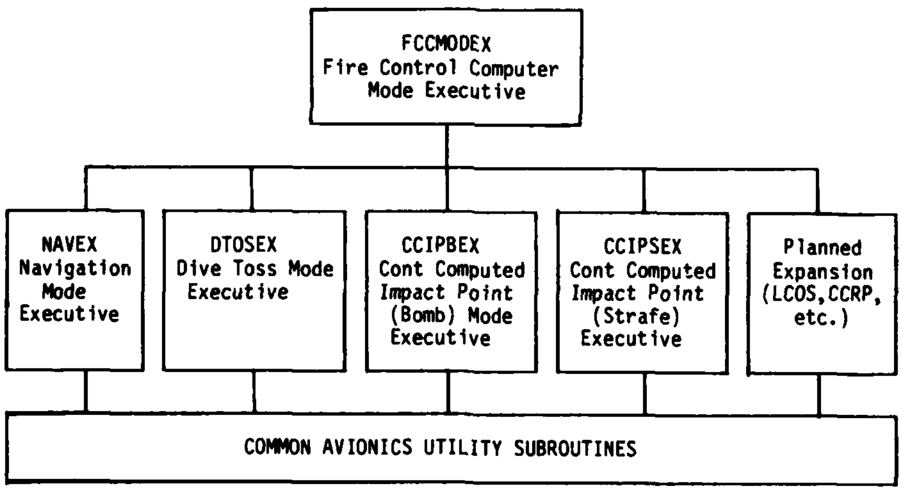
| Aircraft | Simulation |
|---|---|
| 50 | 60 |
| 25 | 30 |
| 12.5 or less | 15 |

Mode, VIP Mode, Snapshoot Mode and LCOS Mode have been added proving the ease of expansion into the air-to-air simulation capability.

The design concept of allowing prioritized growth capability while maintaining a "clean" well structured system was especially critical due to the extremely compressed schedule. The development time for each new avionics A/G delivery mode proved to be greatly decreased, as each mode uses the same avionics utilities subroutines.

In the area of research support, the avionics simulation approach was invaluable in its ease of interface with the ASPT's preprogramming research system since all "FCC internal" variables as well as HUD information were directly accessible in the other simulator general purpose computers. Target tracking and weapons scoring, for example, were directly available to the Student Data System (SDS) and graphics displays at the Advanced Instructor/ Operator Station through shared memory.

This approach was followed to successful accomplishment of all design goals for Phase I within the 300 day schedule. More than fifty F-16 pilots have been trained (with research data collected) in all the visual air-to-ground modes as well as enroute navigation, ILS, takeoff and landing. Air-to-air capability is being added in parallel with visual system updates to accommodate research requirements in this area. Excellent fidelity and training/ research capabilities have been demonstrated.




Simulation Modular Software Architecture

### Software

The desired software architecture was one which could easily support the independent development of specific A/G and navigation modes, thus enabling a smooth, prioritized growth of capability to match research and training requirements. A "top down" structural approach within each mode was applied to take advantage of the similarities between modes; each mode having an executive program which basically consists of an organized series of common utility subroutine calls. Note: Manual

## CONCLUSION

All three approaches were technically sound despite the various difficulties associated with each. Each approach has merit for a particular simulation requirement.

The hardware "stimulation" of the FCC, for example, is ideally suited to a system which is intended for the validation and verification of on-board aircraft avionics subsystems. In a training environment, however, there are design penalties to be considered as a result of the loss of direct avionics system control. System hardware complexity has a major impact on acquisition and life cycle costs as well as reliability/maintainability. The difficulties in supporting conventional training features has a major impact on software and hardware complexity. Even minor updates to the OFP which represent little or no operational change require analysis and will most likely cause software changes due to the relocation of key variables (used for tracking, scoring and initializations) within the FCC's memory. (Singer Co. has spent considerable effort in developing software to support this difficult task for the F-16 production simulator).

In a training research or operational research environment, this approach is extremely cumbersome. The software effort and expertise required for capturing and processing large amounts of FCC internal information or implementing minor modifications in operational characteristics (i.e., mode or Hud symbology, switchology or control function changes) is phenominal. Post-mortum research answers are the result of this type of "hands-tied" engineering situation where the aircraft component (FCC) is in control rather than the simulator GP computers.

The software "emulation" of the FCC has merit in operational research and training/research only if the host GP computer has a JOVIAL compiler. (The source high-level language of the FCC's software OFP). The "emulation" approach could then possibly compete with the hardware "stimulation" approach for OFP software validation if lack of hardware facilities and cost were primary factors. The positive attribute of this approach for simulator applications is that the software architecture and basic integrity of the OFP is maintained. In the "ideal" world of simulation, however, many of the algorithms may be unnecessarily complex and real-time consuming. The integration of this "foreign" software with flight dynamics and advanced training software is also a major software task. Detailed knowledge of the OFP and FCC hardware configuration is needed for an efficient implementation.

The "simulation" system approach to the FCC/avionics simulation affords the most direct control, minimum hardware complexity, and greatest ease of integration with the flight dynamics and advanced training software. Because of these positive features, the "simulation" approach is most appropriately applied to a training/research or operations research simulation effort. In these environments, the penalty of extended software development is more than offset; particularly when priorities can be placed on specific avionics system simulation capabilities and training or research may procede while software development continues on lower priority modes or capabilities. With this approach, critical training or research problems may be defined and solved 1-2 years earlier, minimizing early program aircraft and pilot losses. Ultimate fidelity is not sacrificed and system reliability and maintainability are enhanced.

In closing, the primary point to be made regarding a "stimulate" versus "simulate" design decision is that a good selection is based on the specific projected requirements, cost and schedule for the simulation. Information and recommendations from aircraft hardware manufacturers or facilities whose requirements are the evaluation of aircraft hardware are extremely valuable. The program manager or design engineer must remember, however, that most of these resources have little understanding of the simulation training/research environment and may be fixated on the complexity of real-world aircraft system problems. If validation of aircraft subsystems is not a requirement, a simulation of that subsystem may be more appropriate; particularly when that subsystem serves as a primary processor and communications controller for the entire avionics system, as in the case of the F-16 Fire Control Computer.

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## ABOUT THE AUTHOR

Mr. R. Bruce McCreary is project engineer for the F-16 Avionics simulation program at the Air Force Human Resources Laboratory. He is presently involved with micro-processor application to real-time interface, peripherals, and computational areas of simulation. His staff responsibilities include engineering analysis and support of alternate visual system technology development.

# DEVELOPMENTAL TESTS FOR ARTILLERY ENGAGEMENT SIMULATION

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## ABSTRACT

Engagement Simulation (ES) has filled a training need for maneuver forces by realistically assessing casualties and by replacing fixed scenario exercises with free play interchanges where opponents' actual behavior determined exercise results. Artillery was not integrated into ES, however, and the goal of this research was to develop a realistic and inexpensive ES method for training artillery units. A computational system, which used the data actually set on the guns and employed standard fire direction equipment, was designed to select the probable impact point of artillery rounds. This meant that the behavior of artillerymen directly affected the placement of artillery simulators on the ground. Thirty-six simulated missions were "fired" by an artillery battery during a developmental test. Targets on the ground were assigned to a forward observer and simulators were placed based on the computed impact points. Feedback on mission effects was provided. Results indicated that the artillery system improved its speed and accuracy.

## INTRODUCTION

Field artillery has presented very specific training problems throughout the history of cannon gunnery. These problems have become more acute in current times because of financial and spacial constraints. In years past, when there was a great deal of open land within the United States, there was generally no problem in obtaining enough space for live fire ranges. As the country has urbanized, range limitations have become severe. You need a great deal of land to fire a live artillery piece, and safety constraints prevent fire into areas where maneuver troops are training. The cost of ammunition also has escalated dramatically during the past decade, and this has led to a limited supply available for training purposes.

Due to the limitations in training ammunition and ranges and due to safety constraints, most of the field training within the US Army has been limited to dry firing exercises where men are required to go through the movements of operating their weapon without any potential for feedback as to the success or failure of their fired mission. Live fire is restricted to several exercises per year. The learning literature in psychology has emphasized the importance of knowledge of results in order to obtain performance improvement. You do not receive this knowledge by dry firing exercises, by gun drills, which involve just moving the dials on the weapons, or by displacement exercises, where you set up the weapon, perhaps dry fire, and then move the weapon to another location to see how fast you can do it. In this type of training environment, the only feedback that personnel receive is generally a critique of what they did wrong. There is no possibility for positive feedback. Simulation methods can be very advantageous in a situation where opportunities for "hands on" training through live fire have become increasingly rare and expensive.

A system has been evolved over the past decade for training combined arms (armor and infantry) forces. Engagement Simulation (ES) is the term generally used to label what amounts to a family of training systems. In the early years, ES focused upon the rifle squad and gradually was improved to include the platoon and the company-team organization. There are several major characteristics of Engagement Simulation as it has been used for maneuver forces. The first is weapons effect signature simulation which produced a simulated flash and bang for each weapon system similar to an actual firing. This provides feedback to the firer and cueing to his "enemy" which means that the firer has to take the same action that he would if he had fired at and revealed his position to an actual enemy. The next and perhaps the most important characteristic of ES is casualty assessment. This is a system for deciding who shall "live" and who shall "die" based upon very precise rules which credibly represent the actual effectiveness of soldiers' weapons. Finally, the characteristic which distinguishes ES from traditional field training is what we call the After Action Review. This is a participant interactive type of exercise which occurs after the field action and amounts to facilitating the communication between the two opposition forces. They can review the action and determine the effective and ineffective behaviors in a noncritical setting.

When ES was first developed, a method was required to simulate artillery to the extent necessary so that ground maneuver forces would know that it existed. The focus was on artillery from the viewpoint of the infantryman rather than from the viewpoint of the artilleryman. The method employed for maneuver forces was both basic and straightforward. An infantry commander, for example, would ask for artillery fire at a particular location; a fire marker control center (FMCC) would plot the location on a map and provide directions to individual fire markers.

They were told to go to the requested location and drop artillery simulators on the ground. The location to which they were sent was the same as the location where fire was requested. This was very unrealistic because it eliminated all effects of artillery processing time and the possibilities for error. These can be considerable, especially on the first round fired. This method did not involve any artillerymen except the forward observer, who if he was assigned to the maneuver commander, could request the fire missions.

The research problem was to develop a method to incorporate the field artillery firing system into an Engagement Simulation training program.

The Field Artillery System consists of three main elements. As previously noted, the forward observer is located with the maneuver units and has the task of calling for fire missions based upon the needs of the maneuver unit commander. He sends these calls to the Fire Direction Center (FDC), where computations are accomplished and the data is sent to the final step in the firing system, the gun battery. The gun battery sets the data on their guns and ammunition and fires the mission. The forward observer observes the incoming fire, makes his adjustments and sends this back through the system. This cycle is repeated until the rounds hit the target. In traditional ES, the FDC and the gun battery itself were not involved in any way.

The methodological problem generated by this research effort was how to get the gun battery and the FDC involved. A concept for solution was to develop a method of determining the terminal effects of the simulated round (the projectile fired from artillery), specifically to locate the most probable impact point of that round. This system had to be as realistic as possible, inexpensive, and implementable on the limited range space where units train most of the time at home station. Weapon signature simulation, which is part of maneuver ES, was not required for the purposes of involving the FDC or the gun battery. What we were most interested in was integrating the performance of people who are directly involved in the artillery firing sequence, so that feedback could be provided on the accuracy and speed of their performance.

## METHOD

A standard artillery procedure was already available to provide the basic solution to our problem. This procedure is called replot and is used to determine the location of a target from the data (settings for the guns) that were computed by the FDC and sent to the gun battery. However, as used in standard artillery practice, replot is a relatively time consuming, iterative procedure. It was necessary to simplify this procedure and to acquire the data directly from the gun battery in an accurate and timely fashion. These data had to be sent to a control center, be replotted, and then be sent further forward to fire markers. They could then mark the target, not where fire was requested, but where the fire would have gone given all the inputs of the artillery system.

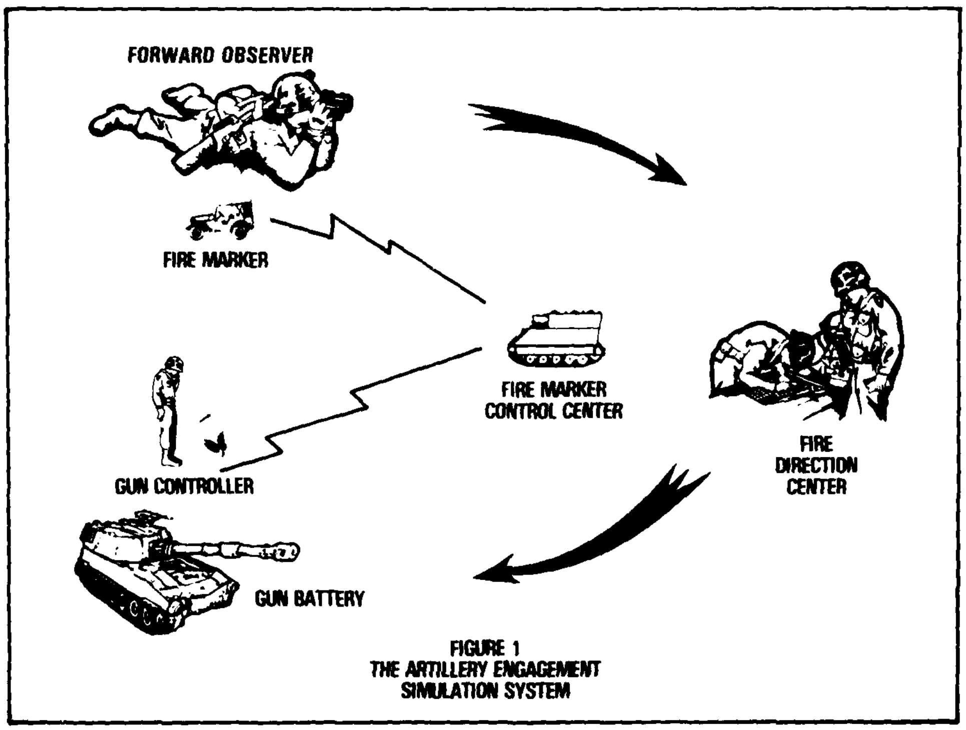


Figure 1. Artillery Engagement Simulation System

The system that was developed is described in Figure 1. Each element of the artillery firing system has a corresponding element in an ES control system. The role of the fire marker, who is in the target area, is the same as it was in the traditional ES except that he is controlled by a fire marker control center (FMCC) which gives him directions based upon computations which will lead him to the most probable impact point. Fire markers are pre-positioned on surveyed points and given a direction and a distance which they can pace off or drive. They then mark their target using "flash-bang" simulators and retire to the closest surveyed point. The work of the fire marker essentially represents the terminal effects of the control system.

Prior to the fire marker ever getting any instruction, the system is driven by what happens in the gun battery. The forward observer calls his mission to the fire direction center (FDC); the FDC does its computations and sends the data to the gun battery; crews set the data on the guns and dry fire their weapons. At that point, control personnel, who remain out of the way of the gun crews, must examine the gun sights and the ammunition very quickly, obtain the data elements, and send this data to the fire marker control center (FMCC). The FMCC performs replot in two ways. First, they use a tradional plotting board approach, which has been available for years but never used in this manner for ES, and as previously indicated is very time consuming. Also, they use a TI59 calculator with a special program that was developed in this research project to perform replot. The reason for doing it two separate ways was to provide cross-checks for accuracy and to evaluate the two methods. When the two plots agree, the data is sent to the fire markers. When the two plots disagree, it is necessary to find and resolve the error prior to transmitting the data. Once the targets are marked, the job of the forward observer, part of the artillery firing system, is to correct his initial call for fire. He therefore provides feedback (especially if he thinks he is not getting what he has asked for) on a continuing basis to the battery through the FDC so that a performance feedback loop exists.

Developmental Tests

In the fall of 1979, a developmental test of artillery engagement simulation was accomplished. Participants in the test included an artillery firing battery, from a direct support artillery battalion, two sets of forward observers, an FDC, and enough personnel drawn out of the battalion to provide for gun controllers, an FMCC, and fire markers. Personnel in the control system were selected because their control tasks were similar to their regular military duties. They were trained in these tasks during a three-day period. All equipment in the developmental test was equipment which is currently standard within a field artillery battalion. Fire markers were issued "flash-bang" simulators which they used to mark the targets on the ground, and communications were set up using standard tactical radios and telephones for the control system so that the FMCC could transmit probable impact points to the fire markers, and could receive the gun data from the controllers in the gun battery.

A tactical setting was written which included scenarios designed to provide a representative array of tasks involved in operating a direct support artillery battery. There were no maneuver troops available; a researcher, who had served as an Artillery Officer, role played as the maneuver company commander. He moved with the forward observer teams, and designated targets during attack and defense missions. During the developmental tests, 36 missions were fired. Each mission consists of an initial call for fire plus all adjustments. This led to 82 separate firings of the battery over approximately a three-day period. All missions were during daylight operations in relatively clear weather.

The procedure for obtaining gun data from the battery was accomplished by randomly checking one of the six guns in the battery, and data were sent forward to the FMCC. Every gun crew was made aware of the fact that its performance could potentially affect the results of the entire battery. Gun controllers were instructed to stay out of the way of the gun crew and to establish a professional relationship with the crew chiefs, such that the data that was sent forward had credibility for the crews, i.e., if the crew did not respect the gun controller's professional ability, the system would not have had any face validity.

RESULTS

The performance of the control system was very important in terms of evaluating the overall training program. The time data were collected using electronic stopwatches from the initial call for fire through final marking of targets. Complete data were collected on 24 missions out of the total 36. Table 1 describes the responsiveness of the control system over those 24 missions by breaking the missions down into four blocks of six missions each and computing the median for each mission. Gun controller delays appear to be minimal from the first series of missions, and do not appear to change appreciably over the four mission blocks. The fire marker control center does improve somewhat over the four blocks. However, the biggest improvement can be seen with the fire markers who begin with an average response time of over three minutes and get their response time down to almost two minutes. By the fourth mission block, it can be seen that the median delay was slightly over three minutes for the control system. The median increase in the third block was primarily a function of fire marker performance, which may have been related to the trafficability of the terrain.

Table 1

MEDIAN CONTROL SYSTEM RESPONSIVENESS (SECONDS)

| Mission Block | Gun Controllers | FMCC | Fire Markers | Overall |
|---|---|---|---|---|
| I | 31.0 | 108 | 216.5 | 377 |
| II | 28.0 | 86 | 177.0 | 291 |
| III | 31.10 | 87.5 | 247.0 | 354 |
| IV | 27.5 | 67.0 | 129.5 | 208.5 |

The performance of the fire marker was related to the distance that he had to travel. A linear regression analysis provided a regression equation: $t=84.07 + 0.87d$. The Pearson correlation between distance and time was 0.73, which was significant ($p<.01$).

During the 82 firings of the exercise, the FMCC transmitted only one error to the fire markers. Five other errors were corrected in cross-checks by the two computers, the one using the board and the other using the calculator in the FMCC. It was found that the calculator method was more accurate in computing the most probable impact point, because it was a precise mathematical procedure. The board plotting involves certain perceptual limitations of the operator. Fire marker accuracy was analyzed for the first time in this exercise. There is no way of knowing precisely whether or not it is comparable to previous ES exercises. The mean cumulative mission error for fire markers was about 75 meters. The mean error per shot was somewhat less than that, about 48 meters. This is within the burst radius of the type of artillery employed, 155mm howitzers, and therefore is not considered extreme.

The critical test of any training system is how it affects the behavior of the individuals or organization being trained. The most important aspects of artillery system performance are speed of delivery and accuracy. Data were collected on these variables for 36 missions.

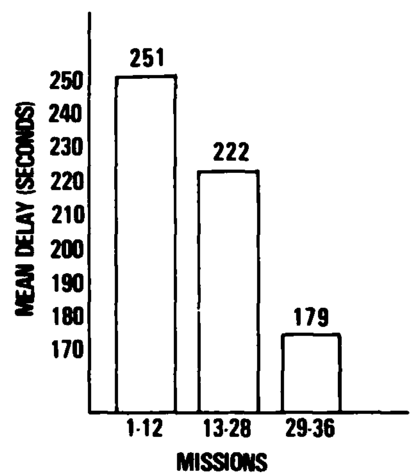


FIGURE 2
ARTILLERY SYSTEM DELAY

Figure 2. Artillery System Delay

The 36 missions fired during the exercise were divided into three blocks of 12 missions, and the mean delay for a call for fire until the first round was delivered on target by the artillery system was computed. These delays did not include the control system time which was subtracted from the overall delay. Figure 2 describes the change in system performance from the first through the third mission block. As can be seen, there is a considerable improvement. The system gets faster as training progresses.

The accuracy of the artillery firing system was determined by the distance between the coordinates requested by the forward observer, who is part of the system, and the impact coordinates computed by the FMCC. Again, any error produced by the control system was not included in these computations.

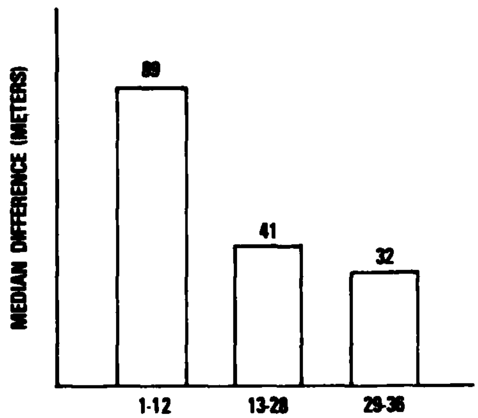


FIGURE 3
ARTILLERY SYSTEM ACCURACY

Figure 3. Artillery System Accuracy

Figure 3 describes the change in accuracy from the first mission block of 12 missions through the third mission block. As can be seen, the greatest improvement occurred between the first and second mission blocks. By the third mission block, accuracy was well within the burst radius of one round of artillery, which means that the unit was performing in a very creditable fashion.

The training system will not be successful if the trainees resist the training. An evaluation of the artillery engagement simulation system would not be complete without some input by the participants. Figure 4 describes some selected items of information that were requested from the artillerymen, who participated in this exercise. They were asked to respond on an eight-point scale from strong disagreement to strong agreement concerning some statements about their training. An average or mean response higher than midpoint of the scale indicates some level of agreement and those below the midpoint indicate some level of disagreement. As seen in Figure 4, the gun controllers had credibility with the crews, and on the average crews felt that the information about their performance made the training more interesting. They also indicated that the controllers did not get in their way while they were doing their

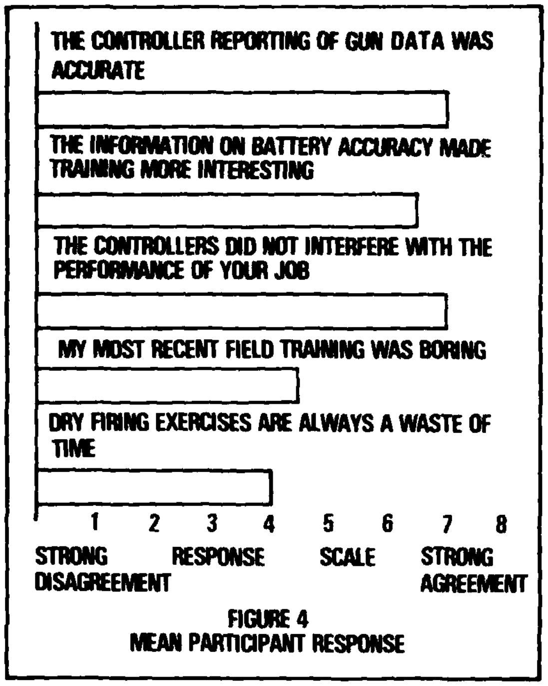


Figure 4. Mean Participant Response

jobs. Two scales that were introduced to see whether or not negative responses were possible indicated that while people did not disagree strongly, they were at least ambivalent to statements such as "my most recent field training was boring," and "dry firing exercises are always a waste of time." Informal comments by forward observers indicated that they considered the accuracy and speed of the artillery engagement simulation system comparable to live fire, because live fire introduces many delays due to safety constraints. They liked the training method better than other non-firing methods such as the subcaliber mortar range, which is very responsive to weather and wind conditions.

## CONCLUSIONS

While this method for integrating artillery ES into a larger simulation training system has not been attempted with maneuver troops due to budgetary constraints, it is believed that the method is functional and will serve to add realism, both for artillerymen and for maneuver commanders. The beauty of this method is that it employs no additional equipment other than what is already in an artillery battalion, and requires few personnel to run it. There's still no technological solution for marking targets other than the one that has been employed over the last ten years, having a man drop a simulator on the ground. Fire markers must be carefully trained or they won't perform in an accurate and timely fashion. Developmental tests have led to the point where there is now an ES training program that involves actual artillerymen on the ground using their standard equipment. This is a big step forward. Hopefully, in years to come, a validational effort can be mounted in conjunction with maneuver troop exercises.

## *ABOUT THE AUTHORS*

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# THE SEMI-AUTOMATIC INSTRUCTIONAL SYSTEM

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## ABSTRACT

This paper outlines Link division's approach to the general training requirements of the B-52 WST, and the specific requirements of the Instructional System. A review of the analysis and design approach is presented, as well as an overview of the resulting Instructional System, including several of the factors which influenced the design and development of the system. Several design goals were established for the Instructional System and, at this writing, the system has undergone several months of limited qualification testing by the Air Force test team, culminating in a production contract award to Link.

## INTRODUCTION

As the developmental phase of the B-52 Weapon System Trainer (WST) program nears a close, a training device has emerged which in many ways reflects the dynamic environment of its airborne counterpart. This paper is aimed at helping the audience understand the evolution of this system.

We will first present a brief overview of the aircraft, and then look at some general requirements for the WST as well as more specific Instructional System requirements. The next step is to describe the resulting instructional system which was developed to meet those requirements along with several other influencing factors.

In a program of this complexity and duration, one expects a certain evolution of design goals and system requirements based upon new data and observed system utilization by line crewmembers. This was certainly the case during the development of the B-52 WST. The additional challenges and frustrations of the competitive procurement also added to the general complexity of the effort. Contributing to this is the complexity of the B-52 equipment, requiring six crewmembers (Pilot, Copilot, Navigator, Radar Navigator, Electronic Warfare Officer, and Gunner).

Classified as a heavy strategic bomber, its primary mission is the delivery of strategic weapons wherever such delivery is deemed appropriate. The physical layout of the aircraft segments the crew as shown in Figure 1. The Pilot and Copilot are positioned in the forward area of the upper deck, and are responsible for the basic flight control of the aircraft. The Pilot, who occupies the left seat, is also the Aircraft Commander, responsible for the overall mission and crew. The aft area of the upper deck is occupied by a defensive team consisting of Electronic Warfare Officer and Gunner, responsible for the defense of the ship from ground and air-based threats such as anti-aircraft artillary, surface-to-air missiles, air interceptors, and air-launched missiles. The lower deck is occupied by an offensive team, a Radar Navigator and Navigator, responsible for the accurate navigation and direction of the aircraft from takeoff to landing and the direction of the aircraft for release of gravity weapons. The offensive team is also responsible for the Short Range Attack Missiles carried aboard the B-52 for use against ground-based threats in an attempt to improve the penetrating B-52's probability of survival.

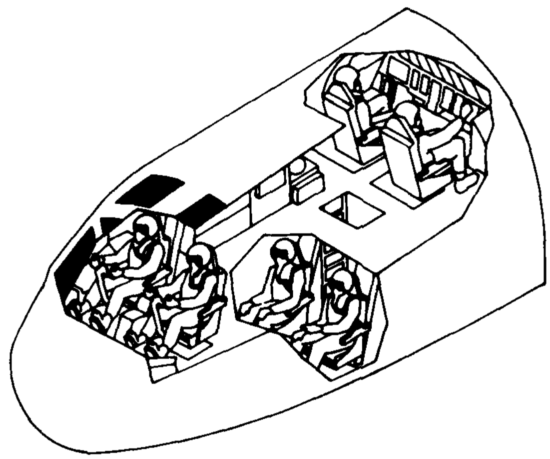


Figure 1 B-52 CREW POSITIONS

The B-52's mission, though simply stated (deliver weapons on a designated target), becomes complicated due to the performance of the aircraft and systems while operating in an external environment of higher (state-of-the-art) technology and additionally due to the intricate coordination of activities required of the crew members.

The prime item development specification for the WST requires the delivery of three separate, but joinable, training devices. A Flight Station with six-degree-of-freedom (6-DOF) motion and digital visual system, an Offensive Station with 3-DOF motion and digital radar landmass system, and a Defensive Station with an interactive threat environment. Each station additionally includes a remote Instructor Station, and a secondary onboard Instructor Station and, of course, a computational system. The physical layout of the aircraft, shown in Figure 2, makes the separation of the crew into three units in a trainer quite attractive. Figure 3 is a schematic representation of the three crew stations which make up the B-52 WST. Since members of the three teams rarely make direct visual contact with a member of another team, the situation in the trainer is not significantly different from that in the actual aircraft.

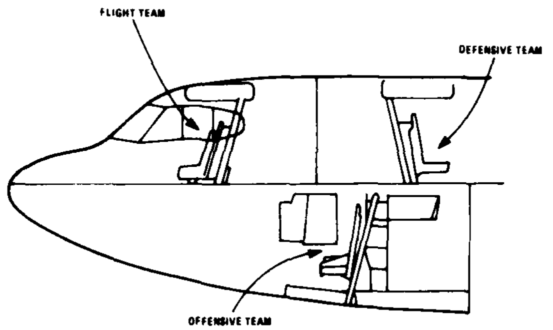



Figure 2 B-52 CREW COMPARTMENTS

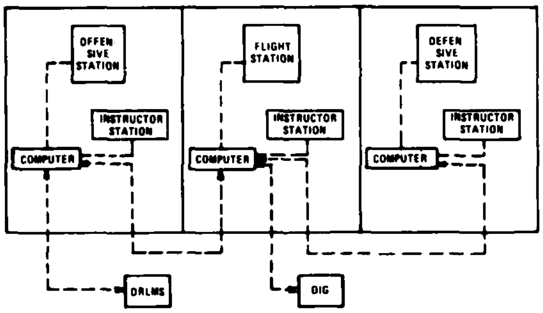



Figure 3 B-52 WST FUNCTIONAL UNITS

Instructional System Requirements/Analysis

The prime item development specification required a system to meet training needs for initial combat crew qualification and for mission qualification and continuing training and to accommodate operation for instruction, proficiency training and evaluation.

Specific capabilities and features included:

1. Remote Instructor Stations for each crew station -- Flight (FIS), Offensive (OIS), Defensive (DIS) -- with each optimized for dedicated operations with its associated student station.

2. Graphic CRT display/function keyboard system to provide for Programming (setup and modification of training mission data); Status of cockpit equipment, student actions, and the training situation; and Plots of aircraft track during various mission phases.

3. Simulator controls for all functions necessary for training.

4. Repeater display for selected equipment, including visual system, Electro-optical Viewing System (EVS) monitor, and radar indicator, as well as selected Defensive Station repeater displays.

5. On-board instructor positions to allow over-the-shoulder instruction and evaluation.

6. Simulation Exercise Control Unit (SECU) to provide the on-board instructor with limited control over the simulation exercise.

7. Instructional Communication System (ICS).

8. Automatic Monitoring of simulation variables and parameters, flight profiles and procedures with hardcopy printout, CRT display, and magnetic disk storage of monitored data for post-mission analysis.

9. Automatic Playback of simulator performance.

10. An automatic radio message system.

11. Automatic malfunction insertion.

12. Capability to record and reset to simulator position and conditions during real-time operation.

13. Freeze/Unfreeze simulated station as well as selected parameters.

14. Hardcopy printout of mission file data and other data pertinent to instruction.

15. Crewmember performance scoring.

Added to these requirements is an additional requirement for analysis of the instructional roles to be filled by the WST, leading to the definition of the basic system structure and specific methods to be used. These specific details as well as overall goals of the instructional system were defined based upon the results of this process. A primary factor in goal definition is the analysis of the skills and activities to be rehearsed in the trainer and the levels of proficiency of those who will be trained. The requirements of the B-52 specification provide a collection of features and capabilities which are meant to support these activities and participants, but in order to properly and effectively implement a system, further study was required.

In the B-52, the primary mission goal and many of the secondary or enabling goals are not rehearsable in the aircraft. This is apart from the normal emergency procedure drills and equipment failure problems which are considered too risky in any aircraft. The analysis of instruction system needs must be grounded primarily on the needs of the crewmembers in retaining a high level of proficiency in this complex environment.

Further, the instructional system designed for the WST requires a significant degree of tactical flexibility. Not only do the methods of modern warfare change frequently, but the basic tools also are subject to development. The promise of the cruise missile and state-of-the-art avionics systems hold the possibility of vast changes in the role of the B-52 crewmember. Since the effects of these new developments on the B-52's detailed training requirements are at present certain, the basic system developed for the WST had to respond effectively and easily at a moderate cost to fairly significant changes in the employment role of the B-52 Weapon System.

For those not familiar with details of the B-52 WST procurement, it was administered by the United States Air Force as a competitive flyoff between the Boeing-Wichita Co. and Singer-Link Division, both of whom designed and built protoype

WST's. These trainers were then both subjected to testing by Air Force personnel, culminating in a final flyoff conducted by actual SAC line crewmembers. Throughout the development, Air Force guidance was severely limited so as to avoid giving an edge to one competitor over another.

As a result, very little official guidance or feedback on proposed modifications and deviations could be provided, and areas of the specification which were goal-oriented could be interpreted in ways which our analysis indicated would provide the most effective system. Other areas which were very specific not only in the goal, but also in specific implementation techniques, were more troublesome, since often more effective means were available. One such area was in simulation of an air refueling rendezvous, where a specific model was described, although alternative mthods not only simplified the problem, but in fact resulted in a more faithful reproduction of real-world events. In the competitive environment, there is considerable pressure to conform to specification dictates precisely, so alternative approaches were examined closely before acceptance or rejection.

The specification, as a primary design source document, provided a wealth of information on the requirements of the system. To add to this source, a number of other data sources were combined to provide an overall picture of the instructional needs of B-52 users. Sources such as Instructional System Development (ISD) Analysis performed for the Strategic Air Command in 1974 provided valuable guidance in evaluating typical task elements and problem areas in the training programs then in existence for new B-52 crewmembers. Other military sources, such as the Education Training Requirements (ETR) document, further enumerated individual task elements for the operational crewmember.

The conclusion reached through this process contrasts the B-52 WST with other multistation trainers. Although the three stations which comprise the B-52 WST are designed for use in independent as well as integrated training, a major factor in their design is the interrelationship of tasks among the crew members. In separated training situations, the instructor is burdened with the responsibility for role-playing to provide the required assistance or hindrance which would normally come from other crewmembers. As the time comes to integrate individual skills into a mission-objective-oriented skill package, the interplay among the crew becomes a major factor.

To fine-tune the mission-critical skills, the true complexity of the mission environment must be allowed to unfold. The situation here is sharply different from that existing in a multi-student system trainer, where a number of students are performing their missions in a completely unrelated way. The coordination tasks for the instructors in an integrated WST are considerable and require direct support in the design of the machine.

Another major requirement exists for rapid and direct transition amoung the available operating modes of the WST. This transition assumes key importance with the realization that WST time is utilized best by developing training scenarios which exploit mode transitions to bring the trainees together for complex mission elements while allowing independent pursuit of relatively non-coordinated tasks.

In developing the design goals for the WST, the primary goals were based upon the complex task structure in the trainees' required skill inventory, and the complex environment in which the crew must be placed. Based upon a consideration of these factors, many secondary or derived requirements emerged which were significant to the implementation techniques used for the Instructional System software. A good example of this is related to the previous discussion of trainer mode control.

What emerges from a study of this problem is a group of central design considerations. These are the fundamental goals which all secondary goals and specific system requirements are built upon. Table 1 reviews some central elements of the WST goal/approach structure. Due to the highly complex task structure which the WST instructor must monitor, his role as an evaluator and diagnostician must be optimized. The required simulation injects the simulated aircraft into a fairly complex environment. To the greatest extent possible, the environment must be controlled automatically, with status clearly and easily reported to the instructor.

Finally, since the mission of the B-52 and the interrelationship of tasks for the B-52 crew is so complex, an easy method must be available

TABLE 1 DESIGN GOALS/APPROACH SUMMARY

| SIMPLIFY OPERATION | REDUCE INSTRUCTOR TASK LOADING | OPTIMIZE INSTRUCTIONAL MEDIA |
|---|---|---|
| O SINGLE KEY PAGE SELECTION | O MISSION SEQUENCE/EVENTS | O CONTROL PANEL CONFIGURATION |
| O COLOR-CODED KEY FUNCTIONS | O MALFUNCTION ACTIVATION AND DELECTION | O CRT DISPLAY ORGANIZATION AND CONTENT |
| O USE OF SPECIAL FUNCTION KEYS | O PROCEDURE MONITORING | O LOGICAL CONTROL INTERACTIONS |
| | O VOICE MESSAGES | O AUTOMATION OF CONTROL INPUTS |
| STANDARDIZE INSTRUCTION | O PERFORMANCE MONITORING AND RECORDING | |
| | O DISPLAY UPDATING | |
| O PRE-SPECIFIED LIBRARY MISSIONS | O CONTROL FUNCTIONS | |
| O PRE-SPECIFIED INSTRUCTIONAL DATA | | |
| O PERFORMANCE STATUS AND MONITORING | SIMPLIFY DATA GENERATION PROCEDURES | |
| O PROCEDURE MONITORING | | |
| O HARDCOPY PRINTOUT | O STANDARDIZED INPUT FORMATS | |
| O CONFIGURATION CONTROL | O PRE-FORMATTED DATA INPUT SHEETS | |
| | O DISPLAY PAGE/DATA CORRELATION | |
| | O DATA VALIDATION | |

whereby careful planning of a training session may be performed prior to the training period, easily recalled for use, and executed in a straightforward manner. Improvisation is tolerated by the system to allow for interactive tailoring of the training situation based on trainee performance, but the key design factor is the persistent notion that the interdependence of the elements in the WST makes any but the most thoughtful changes to a planned sceanario risky and argues for a system which allows thoughtful investment of instructor efforts as a course developer/mission planner before the student arrives.

Thus the primary goal is the reduction of instructor task loading in simulator-unique duties. As a fallout of this priority, the system further must assist the instructor to the greatest extent possible in the gathering of a broad body of data, meaningful in the evaluation of the trainees' performance not only in terms of the quality of results, but also useful in the diagnosis of problem source areas.

## FACTORS INFLUENCING THE DESIGN AND DEVELOPMENT

Early in the analysis phase it became evident that a number of conflicting factors would affect the design, development, and ultimate performance of the Instructional System.

Since it was determined that the primary emphasis would be placed on usability of the system by the instructors, control/operation was an area of concern. It was once considered "sound" human engineering to approach design of controls from the "form follows function" position and provide different types of controls for dedicated functions (e.g., automobile windshield washer/wiper controls should differ from exterior light controls). Each should be optimized for its individual functions but sufficiently different so that they do not confuse the operator.

However, since the operation of each control must be learned, as the number of controls and controllable items increases, consideration of required learning time quickly diminishes the desire for different controls. The need to simplify operation was established as a design goal. As a result, only a few different interface/control functions were specified and the detailed system design was forced to satisfy requirements using the specified functions. Since it is a relatively easy software task to monitor inputs for valid form and sequence, the burden of insuring that inappropriate or accidental use did not result in disaster (or frustrated instructors) was placed on the software. Although manual control of many items was required (and is desirable in some instances) the need to minimize instructor task loading by automation was established as a design goal. The Automatic Mission System was conceived as the mechanism to achieve these reductions in task loading by "programming" events and sequences to control such items as malfunction insertion and deletion, voice message activation, procedure and performance monitoring, external environmental conditions control, and CRT display updating.

The key to developing a useful automatic mission is in planning. Since instructors would be the planners and developers, the system design approach required data generation procedures in a form usable by instructors rather than programmers.

Because of the competitive nature of the program, the WST had to be operational for the start of customer testing. Therefore, the schedule became the primary driver.

Also because of the competition, design direction and approval, normally a customer function, was replaced by a "review and comment" position by the Air Force, and responsibility for design decisions was a contractor function.

Another factor which influenced the B-52 WST development was the contract-required development of a KC-135 trainer. The Instructional System specifications for the KC-135 were very similar to those in the B-52 specification. However, the detailed simulation and training systems functions were considerably different. This implied the highest feasible degree of commonality among systems.

Another consideration was the major and minor system updates which might be required to keep the B-52 viable during the next decade or two. These would require associated modification of the WST, implying a high degree of flexibility.

Additionally, the system complexity alluded to previously in the summary of requirements would be a prime factor affecting the development process. Although not a direct concern of the subject at hand, since the majority of work was in software development, this deserves at least a brief discussion.

Normal software development practice requires that the building of a system proceed through distinct phases:

1. Determine system requirements
2. Formulate design concept/approach
3. Develop preliminary design, function allocation, and interface
4. Formulate system test approach
5. Develop detail design/test criteria
6. Code/test components
7. Install/verify system
8. Integrate/test system with other systems

Although there is always some apparent retrograde motion between phases throughout the development process, the process is manageable with appropriate milestones and constraints identified.

This normally smooth process was complicated by the fact that to meet the schedule it was necessary to start software design and development before the instructional system analysis had completely defined the system requirements. A system which maximized designed-in flexibility was necessary to accommodate late-arriving requirements as well as any future modifications. At the same time, as much commonality among the B-52/ KC-135 stations as possible seemed a necessity.

The general approach taken to developing the software drew from the concepts of top-down design, structural programming, and programming teams. However, much of the rigor associated with these techniques was not applied. Software design started, by necessity, at the top by developing a structure which could accommodate anticipated requirements and perform anticipated functions with minimum impact on computer resources. Generalized systems were developed by a team. This provided several advantages. Programmers obtained general overall knowledge of several systems preparing them for the development to come. As more specific requirements were supplied their implementation didn't require starting from scratch. Also, as priorities changed it was easier to adapt.

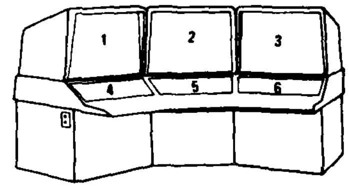
Without the rigor of many detailed design reviews and accompanying documentation to provide management visibility, it became a frustrating environment to manage.

INSTRUCTIONAL SYSTEM OVERVIEW

In reviewing the WST system, it is useful to consider the basic structure of the Instructional System, and consider some of the most influential of the system's features.

The WST instructional system is based on a remote instructor position as the primary operating location. An on-board position is provided, but is viewed only as a secondary location. The remote instructor console, shown in Figure 4, provides the instructor with extensive control and monitor capabilities. The console consists of a functional keyboard, which is used to command the display of various "pages" on the two CRT's of the display system. Switchlight controls in the panel provide control and status information for various functions such as the motion system, trainer mode, and the instructor communication system. Monitors allow the instructor to monitor scenes displayed to the trainee by the visual or radar systems.

In order to describe in a useful way the characteristics of the system, four particularly significant views are presented, each looking primarily at a key system feature.




| PANEL | FIS | PANEL | OIS |
|---|---|---|---|
| 1. | VISUAL REPEATER | | |
| | EVS MONITOR | 1. | RADAR REPEATER |
| | SPEAKER | | SPEAKER |
| 2. | GRAPHIC CRT | 2. | GRAPHIC CRT |
| 3. | GRAPHIC CRT | 3. | GRAPHIC CRT |
| 4. | AIR REFUEL CONTROLS | 4. | |
| | VISUAL/EVS CONTROLS | | EVS CONTROLS |
| | MOTION CONTROLS | | MOTION CONTROLS |
| | MASTER DATA RESET | | MASTER DATA RESET |
| | STATUS/CAUTION LTS. | | STATUS/CAUTION LTS. |
| | LIGHTING CONTROLS | | LIGHTING CONTROLS |
| | EMERGENCY STOP | | EMERGENCY STOP |
| 5. | FUNCTION KEYBOARD | 5. | FUNCTION KEYBOARD |
| | SIMULATOR CONTROLS | | SIMULATOR CONTROLS |
| | TRAINING CONTROLS | | TRAINING CONTROLS |
| | CRT/KYBD ASSIGN | | CRT/KYBD ASSIGN |
| 6. | JOYSTICK/SELECTION | 6. | JOYSTICK/SELECTION |
| | COMM SYSTEMS CONTROLS | | COMM SYSTEM CONTROLS |

Figure 4 B-52 REMOTE INSTRUCTOR CONSOLE

The most fundamental area of interest is the operation of the display system and keyboard. Since the system reliability is of pervasive interest, virtually all status displays and control functions are accessed via the CRT system in order to avoid the maintenance problems associated with hardware instrument repeaters and controls. The Flight Instructor Station keyboard is shown in Figure 5. The keyboard system employs a very simple operating scheme. The main keyboard is used to command the display of CRT "pages" by a single key selection.

Keys are grouped into various classes by location and a color code scheme. The left area contains white programming keys, used for control and setup features such as initialization, visual control, and various atmospheric conditions. These are prime candidates for automation to reduce control task loading. In order to simplify the page fetch operaion, many categories use an index scheme to allow quick advance to the desired page. The keys on the upper right are color-coded blue and command the display of plot function pages.

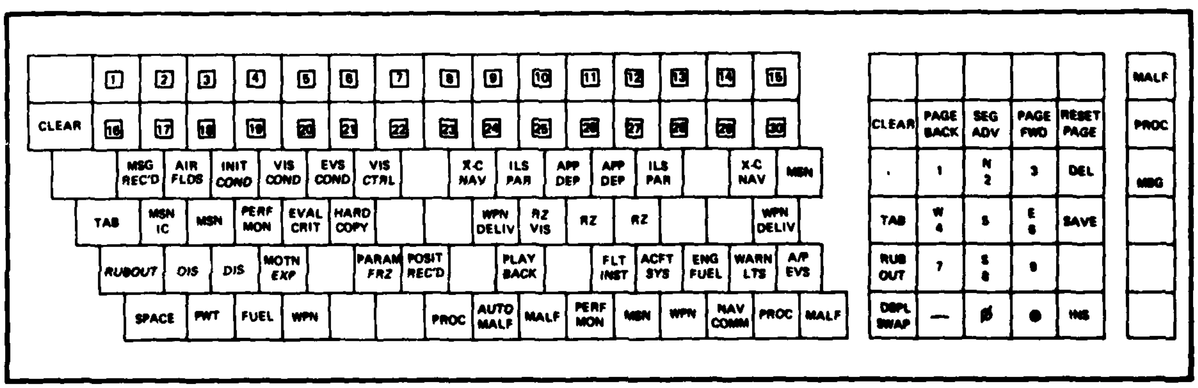



Figure 5 B-52 FLIGHT INSTRUCTOR STATION KEYBOARD

These provide a maplike display of the simulated aircraft's position. This type of display is an aspect of a trainer which goes beyond real-world hardware, since flight instructors rarely have access to such an easily used display of positional information.

The remainder of the main keyboard, color-coded in grey and black, houses keys which command the display of status data. The black-key pages contain training sortie data such as automatic mission, automatic performance monitor, procedure (checklist) monitor, or malfunction system status displays. These are trainer-unique features which are classes of information not available in real-world flight. The grey-key pages allow the instructor to monitor on-board instruments and switches. The use of CRT displays for this purpose provides acurate, easily accessed data with high reliability. Comprehensive coverage insures that the instructor can monitor cockpit activities without actually being present in the cockpit, thus avoiding the effect of an instructor's presence.

Although each of the CRT page formats shown in Figure 6 is identified as a programming, status, or plot style, these distinctions are derived more from customary use than from any system contraint. Different paging (forward and back) advantages inherent in these styles provide for their main differences. The "ALERT" area on each provides a non-page dependent area for important messages alerting the instructor to system activity, such as motion system warnings, automatic system events, or other key milestones. Rather than discuss the specific content of the CRT page collection, a category list has been included in Table 2 to provide some idea of the relative size and diversity of the library with which the instructor interacts.

TABLE 2 DISPLAY PAGE CATEGORIES

| PROGRAMMING | STATUS |
|---|---|
| MISSIONS | F FLIGHT INSTRUMENTS |
| INITIAL CONDITIONS | F AIRCRAFT SYSTEMS |
| AIRFIELDS | F ENGINE/FUEL |
| F VISUAL/EVS | F WARNING LIGHTS |
| PWT | F AUTO PILOT/EVS |
| F FUEL | O RADAR/EVS |
| WEAPONS | O NAV/ASTROCOMPASS |
| O CELESTIAL | O BOMB/AGM |
| O AUTO TO AND LND | O BOMB SCORE |
| O FLIGHT CONTROL | O AGM SCORE |
| PERFORMANCE MONITOR | PERFORMANCE MONITOR |
| EVALUATION CRITERIA | MISSION |
| HARDCOPY | WEAPON |
| MALFUNCTIONS | NAV/COMM |
| PROCEDURES | PROCEDURES |
| MOTION EXPOSURE | MALFUNCTIONS |
| PARAMETER FREEZE | |
| POSITION RECORD | PLOT |
| PLAYBACK | |
| F MESSAGE RECORD | X-C NAVIGATION |
| O RADAR PREDICTION | ILS/PAR |
| O SRAM BY-PASS | APPROACH/DEPARTURE |
| O BNS JAMMING | RENDEZVOUS |
| | WEAPON DELIVERY |

F - FLIGHT ONLY O - OFFENSIVE ONLY

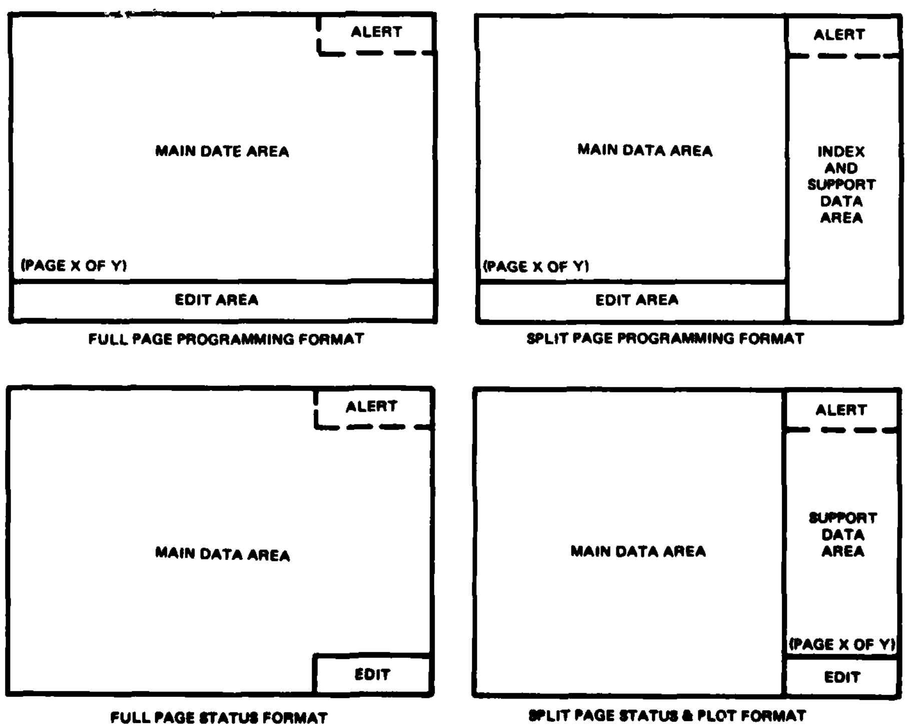



Figure 6 CRT PAGE FORMATS

The wide range of CRT pages provides for interesting diversity, but without the ability to interact, instructors are certainly not going to have the control they need. The small numeric keypad, seen in Figure 5 at the extreme right, and the two rows of numbered special function keys along the top of the functional keyboard provide this ability. Each CRT page item which may be modified is identified by an "item number."

Where variable data is to be edited, such as in the specifying of visibility (for visual scene), the item number is identified via the numeric keypad. This causes the item of interest to be displayed in the Edit area. New data may then be keyed into the system. Here is where various checks are made to detect errors of format, number of characters, and magnitude of the input. In the event that an error is detected, the input is rejected, and an error message appears to inform the user of the error. It is this safeguarding of input at the keyboard, along with the voiding of any fatal keystroke sequences, which provide the foundation for system reliabilty.

Just as many data items require the input of numeric values, many require merely the selection between two states or from an index. This is an area where the WST instructional system departs from the specification in the dominance of the special function keys rather than of a light pen. The use of light pens is fairly common, and is described in the WST specification. The Flight and Offensive Instructor Stations, however, exclusively rely on special function keys to allow selection from menus or to switch between alternate states of boolean items. The advantages of this alternative include increased reliability and ease of use, reduced instructor hand-arm motion, and lower life-cycle cost.

Virtually all system transactions are conducted via these two media, all conforming to a common set of format schemes. Table 3 enumerates a display and control system summary, with operator options and CRT system capabilites. Although the number of interactive fields is large and the different parameters themselves varied, only a small number of distinct data interaction formats are permitted. This commonality of syntax directly supports the reliability, ease of operation, and speed of training goals defined for this system. This allows him (or her) to actually begin using the trainer and develop "on the job." This minimizes the amount of system operation training required so that the bulk of an instructor's training can be devoted to the effective use of a synthetic trainer as a training aid.

TABLE 3 INSTRUCTOR DISPLAY/CONTROL SYSTEM

| FUNCTION KEYBOARD | ALPHA-NUMERIC/GRAPHIC CRT's |
|---|---|
| O PAGE SELECTION<br>PAGE FORWARD/PAGE BACK<br>RESET PAGE<br>DISPLAY SWAP | O FORMATS<br>FULL PAGE (12"H X 16"W)<br>SPLIT PAGE (12"H X 12"W, 12"H X 4"W) |
| O DATA MODIFICATION<br>NUMERIC PAD<br>CLEAR/TAB/RUBOUT<br>INSERT/DELETE/SAVE | O PAGE TYPES<br>INDEX<br>SINGLE PAGE<br>MULTIPLE PAGE |
| O SPECIAL FUNCTION KEYS<br>PAGE SELECT VIA INDEX<br>DATA MODIFICATION<br>SUB-SYSTEM CONTROL | O PAGE CATEGORIES<br>PROGRAMMING<br>STATUS<br>PLOT |
| O DIRECT DATA ACCESS<br>MALFUNCTIONS<br>PROCEDURES<br>MESSAGES | O APPLICATIONS<br>SET-UP AND CONTROL<br>EQUIPMENT STATUS<br>TRAINING STATUS<br>MISSION PHASE PROFILES |

Another key area of WST performance is in the direct control by instructor/operators of the mode or degree of integration of the WST stations. Instructor control of the trainer must be simple, quick, minimally error-prone, and most important, extremely reliable. The system must also insure that no instructor's lesson is interrupted by another station operator. The system developed reflects these requirements in its operation. Mode changes in an upward direction -- i.e., Independent to Integrated (all three stations together) -- require the consent of the instructor at <u>each</u> involved station. No effects of a mode change <u>are</u> felt at a station until its instructor consents by depression of a mode selection switchlight.

Three switchlights, one for each mode, are used at each station. The software which operates behind this simple exterior is of considerable complexity. Since a number of request and status flags are used to communicate each station's situation, and further, since a given station may experience momentary losses of communication with the others (or complete failure), the transfer of status data is continuous rather than based on change. This precludes any "out of sync" situation due to a missed signal. Further, automatic "down-mode" is designed in. If a system failure occurs at one station, the remaining "healthy" systems do not continue to look for data from the failed station, but rather step down to the next lower mode.

Another key software characteristic is a data priority system. Since each station has the capability of operating as a stand-alone device, each computes all parameters required for its simulation environment. Each station has specialized areas where greater detail is required. but in general, when the stations are combined to form the Integrated WST, many parameters are computed in all three computer complexes. Consider latitude/longitude and weapon load. All three stations compute position based upon flight vector inputs. Both the Flight Station (for weight and balance) and the Offensive Station (primarily for weapon delivery gear) maintain a library of weapon loads and track real-time weapon status. To avoid confusion and anomalies during joinups and for initializations in Integrated mode, priority is assigned for each parameter to the station most concerned or involved with that given piece of data. In our examples, <u>Flight</u> controls the latitude/longitude pair, <u>while Offensive</u> controls the weapon load. A system is <u>currently</u> envisioned which allows the designation of parameter priorities in real time by the instructor. This promises to inject even more flexibility into "mulit-mode" mission joinups.

In the course of the discussion we have seen that a considerable portion of the CRT/keyboard system capability is utilized for control of the simulation and training enviroment. The desire for a system with wide ranging flexibility, very simple operation, and low instructor task loading provides a considerable challenge.

The extensive use of automation in eliminating instructor interaction and reducing task loading in the setup and control of the trainer's simulated environment was desired by the Air Force. This is an area where the flexibility for system configurations and training session events is of a strategic rather than tactical nature. By using a system which formalizes required data specifications, but allows a wide variety of data, one can reduce the instructor's real-time task, provide great system flexibility, but also allow for extensive compatibility testing and development of the situations produced. The embodiment of this concept is the use of a mission data base to specify the environmental, task-related, problem-related, and evaluative characteristics of a training session.

By setting forth the characteristcs of a session in advance, the complex interelationships in the crew task structure may be monitored through the thoughtful creation of a problem scenario, complete with appropriate procedural and performance-based evaluative monitoring.

As noted earlier, the intense intertwining of tasks in B-52 crew activities requires that training problems and monitoring techniques be extremely well planned and coordinated. Automatic systems to monitor crewmember performance in checklist procedures, weapon delivery accuracy, and navigation accuracy against recorded parameter values are all included in the WST, but in order to control these features, the WST Mission System was developed.

The Mission System may be viewed as "automatic" in that it performs a host of functions with virtually no help from the instructor. During a training session, having selected and activated one of the available missions, the instructor is free to observe as the system unfolds the problems in the selected lesson plan. The system controls the insertion and deletion of malfunctions, the monitoring of checklist procedures and parameters, and the transmission of digital-voice messages. Other options allow the control of simulated environmental systems such as visual system conditions, wind, atmospheric pressure, turbulence, and temperature.

The system operates by reducing the entire WST mission to a series of elements called maneuvers and still shorter elements known as segments. This structure may be seen in Figure 7. Maneuvers are "sub-missions" which include a complete set of initialization data. This allows a mission to be entered at any maneuver boundary rather than requiring that a mission always start at the very beginning. The basic operating unit of the mission is the segment. Segments are started and ended by the successful fulfillment of conditional statements. Activities within a segment, whether it be a malfunction insertion, a wind change, or a parameter-set activation, are triggered by the reaching of some parameter's required value. The Mission System is the framework of real-time programs which operates to make this happen. The real structure for the training session comes from the data upon which the Mission System operates. The parameters to monitor, the malfunctions to insert, all the system initialization data, and, most importantly, all of the trigger parameters and threshold values are the Mission Data Base.

In considering the Mission Data Base, a fundamental architectural quality of the WST is illustrated. Wherever possible, software has been developed which utilizes a data base in carrying out its activities rather than doing so through the use of specific data implicitly written into the simulation programs. Areas which utilize this structure are numerous, and impact the total system by allowing considerable change potential without the need to alter simulation code. Implementing this scheme required that real-time programs fetch and operate with data files placed on the operating disk-packs by off-line data generation processors. The system, therefore, cannot be considered as the real-time control programs, status displays, and data bases alone, but must also include the off-line processors which build the data base, and the planning procedure. This is one reason why the "automatic" Mission System, and hence the Instructional System as a whole, is better thought of as "semi-automatic." The lure of carefree operation of the real-time lesson carries with it a subtle but inevitable snare.

The Mission lesson plan must be painstakingly and precisely prepared. Events are planned which develop into the desired scenario, and then they must be predicated on appropriate parameter triggers so that the mission flows in spite of student errors. Not an impossible chore, but one which requires complete and thoughtful planning. Who better to do this than the instructor himself? Therefore, the Off-Line Mission Generation processors accept planning data which has been transferred directly from planning forms designed to be used by WST instructors. The listing produced by the processors reprints the mission data base with error messages for illogical or out-of-limit inputs in a format similar to that used on the form so the instructor can review it for errors and make corrections as well as use it in test-flying the mission. The only steps in mission generation requiring computer support are the running of the processors and copying of the data are base files to the real-time operating disk, tasks which take

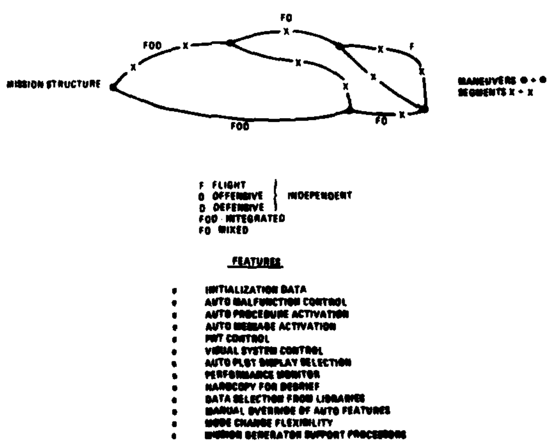



Figure 7 AUTOMATIC MISSION SYSTEM

only minutes. No software support personnel are required. Air Force instructors using the system during qualification test had good results with extremely short training.

An added dividend from the use of this structure is the easy adaptability to new tactical scenarios, new aircraft equipment, and developmental error correction. Although new aircraft equipment may require the alteration of simulation programs and additions to Instruction System monitoring modules, design of scenarios exploiting new capabilities or new tactical doctrine is easily accommodated. This important feature has already proved useful during WST development.

Because considerable development effort has been continued throughout the testing phase, various bits of new information have been accumulated which caused the content of data base structures to change. The use of this structure continues to allow a high degree of flexibility in the system, and provides system designers with the ability to defer many specific scenario decisions which were not supported by solid factual or clearly decisive information.

One of the most significant shifts in WST design philosophy has been the elevation of the Mission System as the prime instructional data source for the trainer. This can be seen from two considerations.

First, the complex interaction between the task activities of the various crewmembers and the high level of simulation-unique control capability argue for a carefully planned lesson plan to fully exploit the system even for the most basic of part-task training. This holds true for just about all elements of the operational skills inventory of the B-52 crewmember.

Second, the Mission Planning task has proved to be easy enough to permit the development of mission data bases for almost any and all purposes. The mission data base is easily adaptable to a data base consisting of segment after segment of takeoffs, refuelings, bomb runs, etc. The mission data base, then, is more accurately viewed as a "training sortie" data base rather than being limited to a "mission" which brings to mind the typical Strategic Air Command sortie. Thus the WST has emerged as a "mission" trainer, with training sessions based upon carefully planned lessons, automated execution of these lesson plans, and maximum use of the instructor/operator for fine-tuning of the trainer's responses and evaluative observation.

In order to meet the challenges of the B-52's complex instructional requirements, the automation of training lessons was required. With this comes the need for careful and insightful planning. Although we offer a highly structured and promising training tool, the value lies in the planning. The entire thrust of automation is not only structure and order, but also the freeing of the instructor. Here we can see the other challenge. The instructor can no longer satisfy his responsibilities by operating the trainer, since that's being done for him. He is now challenged to observe, diagnose, and advise -- in short, to instruct. This is a second reason to discard the notion of the "automatic" instructional system. At best one can strive for a semi-automatic system, and the best system is only a tool in the hands of an instructor. It requires two men in the "man/machine interface," one at plan-time, and one at run-time. Both play such an intimate role in the success of a training exercise that it is not unfair to regard them as parts of the overall system.

Although the competition is over, there is continued development in the WST, making improvements in the design for follow-on production units. Two key design enhancements which are anticipated will be briefly presented to conclude this report.

Observations and comments during Air Force qualification testing, both from test crews and from previously untrained Link personnel, seem to indicate that in spite of the volume of data available to the instructor*, the CRT Display/Function Keyboard system operation is relatively easy to learn. However, to properly utilize the available data in a training situation will undoubtedly require a significant learning period. Two basic improvements to this system have been proposed: 1) a rearrangement of page access keys to provide more obvious and quicker access to the most often used pages, and 2) a specially formatted instructor handbook to aid in using the system capabilities more effectively. The automatic procedure monitoring system, although compliant with the specification requirements, did not seem to provide sufficient information for an instructor at the remote console to determine the student's actions in performing many of the procedures. For example, since the procedure monitor only observed the programmed checklist steps and logged them when detected as complete, the student could inadvertently operate other controls which affected his performance on the procedure without the instructor being aware of the action. Also, when considering the large number of published procedures, about 143 on the Flight Station alone, and the probable future change activity, keeping the procedure system current with the aircraft would become a major effort.

An alternate system which meets some but not all requirements, but which promises to alleviate

*The CRT Display/Function Keyboard system, which is the primary man-machine interface, contained the following items and quantities for the FIS and OIS:

| ITEM | FIS | OIS |
|---|---|---|
| CRT PAGES | 166 | 139 |
| INTERACTIVE ITEMS (LESS MALFS) | 914 | 1055 |
| SYSTEM MALFUNCTIONS | 1424 | 629 |
| STATUS ITEMS | 929 | 1592 |
| TOTAL # VARIABLES | 3267 | 3276 |

most of the problems whith the current system, is being investigated.

Although configuration control of software during the prototype development was generally better than on any other recent simulator, if the full complement of 17 B-52 WST's is produced, the need for a much more automated process is evident, and such a process is being pursued.

The design and development of a Weapon Systems Trainer (WST) for the B-52 in the environment of a competitive procurement was both challenging and frustrating. Since the primary objective of the WST is to aid SAC Instructors in the continued training of combat crewmembers, the success of the trainer and the fulfillment of the major goals will be best judged after a period of actual training exposure. We are anxiously awaiting the opportunity to further develop this system.

## ABOUT THE AUTHORS

R.A. Hansen is a Senior Systems Engineer in the Training Systems Engineering Department at the Link Division of the Singer Company. He has been involved in the identification of instructional requirements and the design of instructional features for the B-52 WSD during the two and one-half years with Link. Prior to this, he spent six years with the Military Airlift Command (MAC), U.S. Air Force, as a navigator instructor/evaluator at Dover Air Force Base, Delaware.

He holds a BS degree in aeronautical engineering from Rensselaer Polytechnic Institute (RPI) and a MA degree in business management from Central Michigan University.

R.S. Reese is a Staff Engineer at the Link Division of the Singer Company, working within the Training Systems Engineering Department. He has been responsible for leading the software development effort for the B-52 WST instructional system. During his thirteen years with the Link Division, he has been involved in the design and development of various trainer-unique features, including graphic display applications, reset/replay systems, and student monitoring capabilities.

He received a BS degree in mathematics from Mansfield State College (MSC) a MS in computer sciences from State University, New York (S.U.N.Y.).

# SCENARIO DEVELOPMENT FOR THE FIREFINDER OPERATOR AND MAINTENANCE TRAINER

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ABSTRACT

This paper analyzes the methodology used for scenario development as learned from the Firefinder Radar Trainer. First, an overall concept of the operational and maintenance trainer is given with special emphasis on the scenario training package. The training effectiveness of the system is demonstrated by reviewing the transfer of knowledge tests conducted with the actual system. The management of the scenario data base is described, stressing the use of the Chief Programmer Concept, the reuseability of the data elements, and the adherance to an effective configuration control plan. The characterization of three levels of training complexity as designed in the scenarios is also given. Next, several training schemes are suggested that make the maintenance trainer a cost-effective device. Emphasized are special CAI/CMI techniques used to transform the simulator into an effective trainer.

## INTRODUCTION

The purpose of this paper is to analyze the methodolgy used to develop scenarios for the Firefinder Radar Trainer. The trainer was developed under a Naval Training Equipment Center contract, managed by PM-TRADE, for the Field Artillery School at Ft. Sill, Oklahoma. The scenario is that group of data necessary to process a student's response, cause a student station stimuli to occur, and provide error and message data for evaluation at the instructor's station. The scenario allows the student to learn in a truly advanced training environment.

### Firefinder Radar Description

The Hughes Aircraft Company AN/TPQ-36 Firefinder Radar is a portable surveillance system used for detecting mortar projectiles. This radar provides first round detection and pin point calculation of battery and impact coordinates. This information is displayed on a tactical map so that a radar operator might review the data before transmitting the information to the command post via the TACFIRE link. Figure 1 shows the radar as emplaced. Figure 2 details the operational panel within the shelter unit.

### Task and Skills Analysis

The tasks and skills analysis (TASA) was performed and determined the following training requirements for the radar operator and the organizational maintenance technician:

Simulated AN/TPQ-36 Operational Exercises

a. Power-on sequence

b. Computer program loading operations

c. Initialization operations

d. Hostile fire operations

e. Friendly fire operations

f. ECM countermeasures

g. TACFIRE operations

h. System shutdown sequence

i. Clearing system or on-line fault indications

Simulated AN/TPQ-36 Organizational Level Maintenance Exercises

a. Loading individual off-line diagnostic tests

b. Troubleshooting central processor unit/input output controller and memory malfunctions

c. Troubleshooting xmtr low-voltage assembly malfunctions

d. Troubleshooting SYSTEM +28 voltage distribution

e. Troubleshooting ac prime power distribution

f. Adjusting shelter, receiver/exciter, beam steering unit, and xmtr low-voltage power supplies

g. Isolating a fault to a defective low-voltage power supply

h. Aligning the signal processor analog-to-digital (A/D) converter

i. Performing the WLU map position (northing) alignments

### Trainer Design Approach

Based on the TASA requirements, a trainer was developed to realistically simulate the man/machine interface found by the operator and maintenance personnel in the actual radar systems.

Figure 1. AN/TPQ-36 Firefinder Radar

Figure 2. Radar Operational Panel

Figure 3. Firefinder Trainer

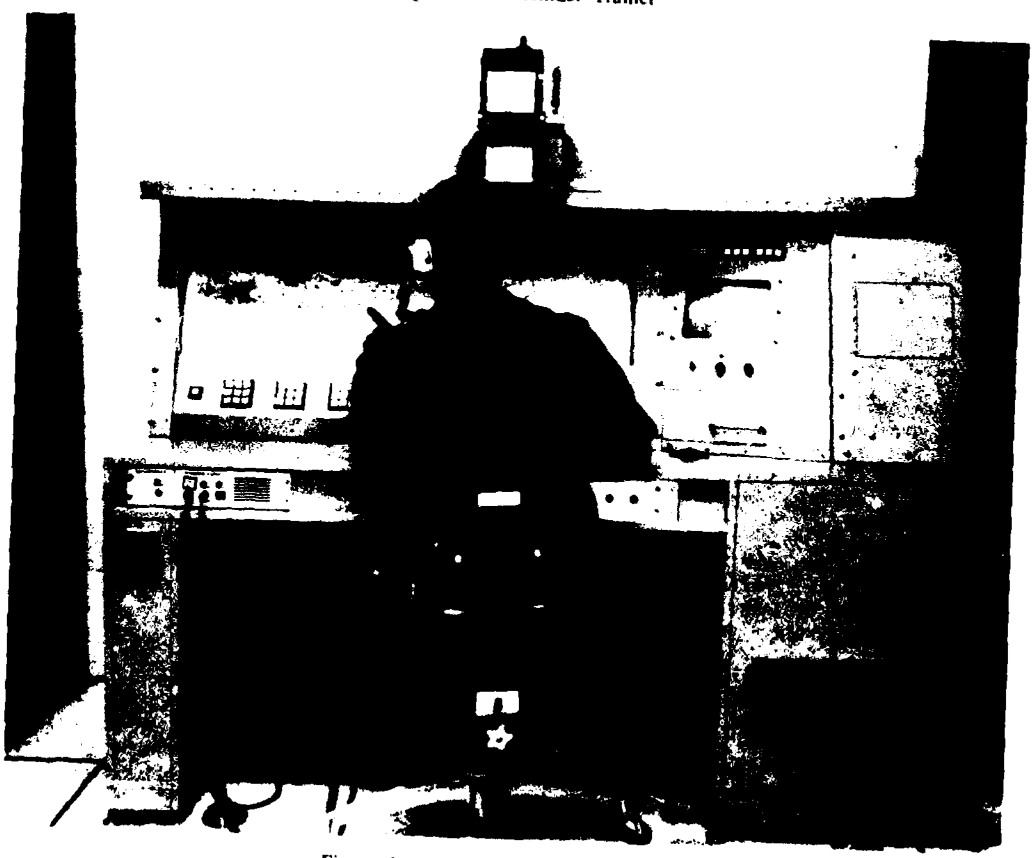

Figure 4. Operational Panel Simulator

The trainer design provides the capability for control of six student stations by a single instructor. Any combination of operator and maintenance technician students can be trained with continuous computer-managed instructor monitoring. See figures 3 and 4 for a representation of the trainer system.

The system provides the capability to simulate the Firefinder shelter and trailer indicators, switches, meters, data readouts, and other physical factors necessary to enable the desired training to occur. The student learns the various skills using a self-paced training exercise selected by the instructor to satisfy the current course curriculum. Once the exercise is initiated by the instructor, the computor will respond to each student action by simulating each Firefinder functional area.

As the students progress through the exercises, the computor provides the instructor station with student station "alert" data, and detailed "performance evaluation" data. The monitoring capabilities include detail display or printout of student actions, historic student data, and continuous display and recording of the student progress data. These features help to minimize the instructor load.

## Role of Instructor

The instructor has the option of freezing the exercise, communicating any learning difficulties with the student using provided audio channels, and then continuing the exercise from the point of interruption or restarting from any point in the exercise. Any errors that the student makes are displayed at the instructor's station along with continuous updating of the student's percent accuracy, percent complete, and percent of the time standards met within the scenario-established criterion.

## Software Approach

The software for the Firefinder trainer incorporates the data-base-driven approach. In this approach, the OPERATIONAL COMPUTER PROGRAM (OCP) consists of generalized processing functions, coordinated and directed by the data base. The response to any input can be altered simply by changing the data base. This data-base-driven design provides greater flexibility in defining training situations, allows diagnostics to be done on-line, and greatly reduces costs and implementation time for modification. Figure 5 illustrates the data-base concept.

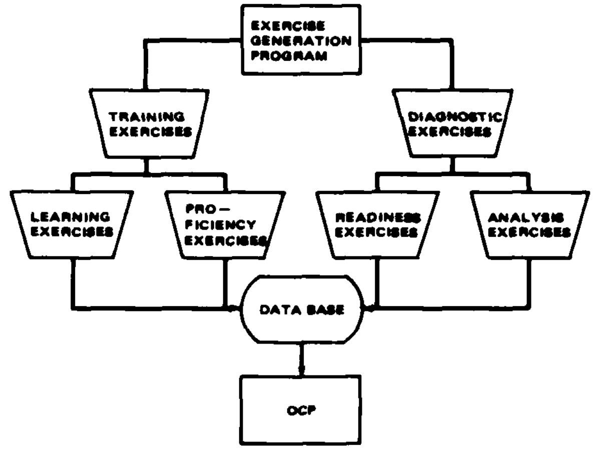


Figure 5. Data-Base-Driven Software Design

Many changes may occur over the life cycle of the trainer as a result of Firefinder production changes or refinement of training objectives. Thus, update costs are a very significant design consideration. The data-base-driven design will accommodate most of the changes by data base modification which, historically, is much less expensive than software modification.

The trainer software, which makes up all the modules in the OCP, performs all of the functions in the trainer system that are not specific to a particular training objective. Examples of the functional capability of the OCP include printing evaluation reports and processing the scenario data. Figure 6 is a top-level heirarchy chart describing all of the functional areas within the OCP.

## Scenarios

A scenario is a group of event forms which direct the fortran-based software package (OCP) to drive the various hardware devices. The scenario is the data that the OCP uses to process student responses, and is training objective specific. The scenario data base is that accumulation of all the training exercises which interacts with the student through the OCP. Each individual scenario will present a stimulus to the student and provide the appropriate response to his action based on the desired training objectives of the task to be taught. The scenario data base is structured in groups of families which represent the operational modes (initialization, hostile, friendly, ECM, zones and combined) and maintenance modes (equipment status tests, circuit card alignment, fault isolation tests, and power status).

# FEATURES OF THE DATA BASE PACKAGE

The Firefinder trainer scenario package was developed by borrowing software development techniques already in use and incorporating novel concepts to improve the efficiency of the authorship. This section will highlight the CHIEF PROGRAMMER CONCEPT, the scenario family breakdown, the three levels of training complexity, the reuseability of data elements, and the configuration control techniques. These principles serve to increase the efficiency of the scenario creation, and aid in giving the program management office clearer visibility in the data base development phase.

## Chief Programmer Concept

The Chief Programmer Concept was first developed at International Business Machines Corporation. The data base generation effort has borrowed heavily from this scheme of group organization. The scenario creation responsibilities revolve around the subject matter expert (SME), who is typically the most experienced scenario creator in the staff (In the software analogy, this would be the chief programmer).

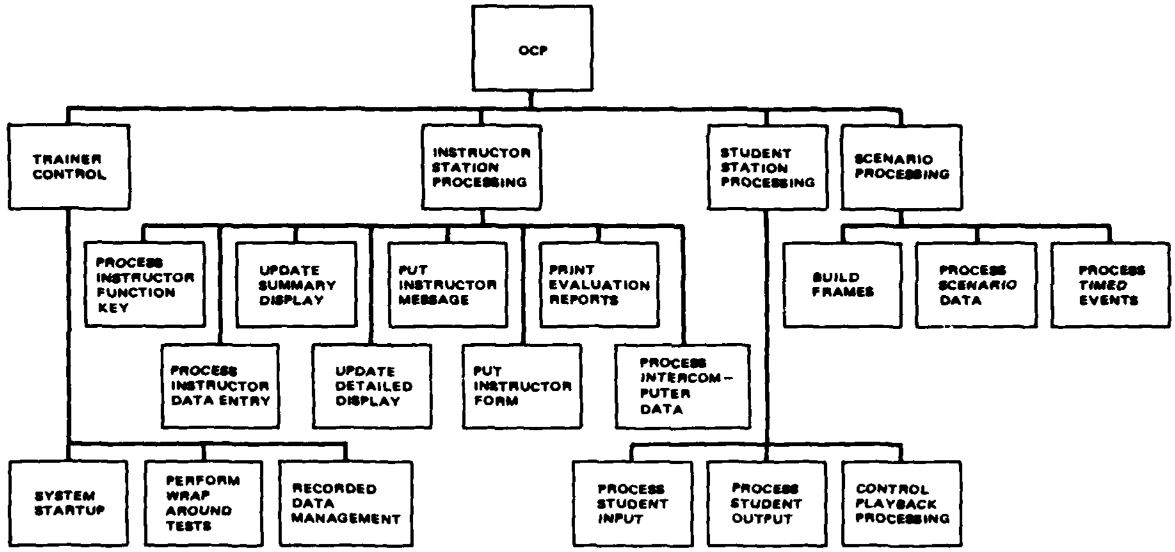


Figure 6. OCP Top Level Hierarchy Chart

The SME's job is to compile the research accomplished by others on the operational characteristics of the prime system, and develop a pivot scenario which serves as the skeleton for all other scenarios in the data base package. This master pivot design incorporates all operational emulation characteristics and excludes specific grading criteria and student timing requirements.

Other scenario creators in the group observe and aid the SME in this pivot design. After this interaction, they will have the knowledge to transform the top level pivot design into the individual scenario versions which meet the specific training objectives required of the system. Apprentice scenario creators work with and learn valuable creation skills from the SME and work directly with the other members of the group on the total data base design, instead of completing a more minor design task on their own.

Other members of the group include a librarian/technician, test coordinator, and business manager. The librarian enters all scenario data into the computer and performs other clerical and configurational assignments for the group. The test coordinator's job is to interface between the scenario creation group and the system test personnel. By observing the design methodology of the data base development, he can communicate testing criteria to the test group so that they may best validate specification adherence and exercise repeatability. The business manager has significant technical background and managerial experience. His job is to act as group manager, but not as the technical design director. The business manager typically schedules time and activities of several other groups, usually the systems test group and courseware development group. He also presents progress reports at the numerous program and division management meetings so that the SME can dedicate most of his time towards design efforts.

The Chief Programmer Concept promotes optimum efficiency in scenario authorship due to maximized reuseability of the data elements and minimum risk of duplication of effort among individual scenario creators. This results in substantial savings in core requirements and development time, thus any exercise update effort is greatly simplified due to the scenario design concepts being universally understood throughout the group.

## Exercise Families

Another method used in data base generation is the family design approach. Using this scheme, all training objectives forwarded by the TASA are separated into functional groups called families. Each scenario within a family incorporates training objectives which are logically related. The SME then designs a pivot scenario for each family while the apprentice authors alter the pivot to suit the training objectives of each task to be demonstrated. The pivot is altered by adding specific data entry grading, target profiles, and customized Computer Assisted Instruction (CAI). In this way, the standard operating procedure is universal within the scenarios of a family and grading criteria can be effectively made more stringent from one scenario to the next.

The pivot for each family serves as a "free-play" scenario which does not exhibit lock-step training objectives. These scenarios allow the student to energize any switch, enter any function code, run any program, or select any feature normally found on the prime system. No grading of data entry is incorporated; however, any normally illegal action is flagged as such.

Each scenario within a family becomes progressively more difficult. At the same time each scenario is composed of 5 different options, each option requiring the student to enter slightly different data. However, each option incorporates the same level of difficulty as other options in the scenario. This provides several options to the student for reinforcement training at the same level of difficulty. Figure 7 clarifies the multiplicity of options that are available.

HOSTILE SCENARIO FAMILY

Exercises (Progressively more difficult)

| | | | | | | |
|---|---|---|---|---|---|---|
| Options (varied base of student entered data) | 8A | 9A | 10A | 11A | 12A | . |
| | 8B | 9B | 10B | 11B | . | . |
| | 8C | 9C | 10C | . | . | . |
| | 8D | 9D | . | . | . | . |
| | 8E | . | . | . | . | etc. |

Figure 7. Multiplicity of Exercise Options

## 3 Levels of Complexity

Each family incorporates 3 levels of training complexity in order to expose the student to progressively more difficult tasks. The grading categories which can exist in all three levels should be described first. The scenario can designate a student action as a not-allowed response, which is not down-graded, as it is normally a part of the actual system. This category was created to keep the student from taking alternate paths that are not included in the training objectives. Once such action is taken, the student is prompted with the letters "NAR," which forbids proceeding in the exercise until cleared from the display. Two types of error classifications exist that are down-graded. A non-critical error is that category designated by the scenario to reflect data which was incorrectly entered or an undesired action which was taken by the student. A critical error is that category reserved for switch actions which are more severe in nature.

The primary level presents few complex tasks and is characterized by a very narrow path of acceptable switch actions, with undesired paths being not-allowed. For example, the single target profile is characteristic of a primary level hostile scenario. Lenient time and grading standards are incorporated with automatic back sequencing (for example, reprompting) on incorrect student actions. Expected action messages are sent to the instructor for each step, while instructional messages referring to the appropriate technical manual page are sent to the student if an error is made. Critical errors will evoke buzzer alerts and caution messages for these potentially dangerous or harmful actions.

Intermediate scenarios are characterized by more complex learning environments, such as multiple target profiles in single mode form (hostile or friendly mode). More paths that were designated not-allowed in the beginning scenarios are now possible, and the student has the flexibility of learning new function codes that are normally a part of the actual system and is not down-graded in this exploratory training. CAI messages are utilized for incorrect responses but no automatic back sequencing is employed. CAI messages are also used in association training. As an example, the student is told at the beginning of the exercise to switch frequencies if jamming is encountered. Later in the exercise, when jamming occurs, he is graded on his ability to remember those instructions. Intermediate scenarios also incorporate tighter time standards than those used at the primary level.

Advanced level scenarios are characterized by a task complexity level equal to that which might be encountered in the battlefield. The student is presented with a combination of situations and tasks that were previously presented in singular form, that is, he is now experiencing a multi-stimulus-response arena. Typical advanced scenarios present multiple targets with jamming, priority tracks, censor zones, and interlocked hostile and friendly processing. Students are forced to make decisions based on environmental factors. As an example, he should know to change frequencies when jamming occurs, without instructional messages. All paths are allowed and total system emulation is incorporated. Time standards meet the ultimate training objectives of the course. No intervention by the instructor is available via manual back sequencing. The advanced scenarios are typically run as proficiency exercises because the instructor will be paying close attention to the percent complete field (Were all tasks performed?), the percent accuracy field (Were any errors made?), and the percent time field (Was the student fast enough?). Based on this performance data, the student will pass this family, be retested on another proficiency exercise, or be rerouted to an intermediate exercise.

## Emulation

As an aid to scenario generation, the OCP incorporates an optional emulation of all switches found on the trainer. If the option is exercised, the software will automatically give a response to the student, which is the exact simulation of the response of the actual system. As an example, when a circuit breaker is turned off, the OCP will automatically extinguish all lights on the trainer which would normally be powered by that circuit breaker. This emulation option saves the scenario creator from having to define the normal response to a switch action. If the scenario creator desires a switch response different from that

exhibited in the real system, the emulation option is not used, and the desired response is specified using the appropriate equipment forms. Examples of the emulation not being used would include faulting of hardware and customized CAI.
More complex operational emulation of the characteristics of the prime system must be designed by the scenario creator. In the trainer, cues presented to the student and his responses are identical to the actual radar system and are represented uniformly to each trainee. Data for these scenarios are derived from the actual operation of the AN/TPQ-36 radar system which is currently being developed by Hughes Ground Systems Group.

Both the operational and maintenance scenarios simulate the operation of all the function codes (which are used to activate the various features of the system). The alphanumeric and graphic simulation includes B-Scope zones, header messages, function code prompts, and line priority cues. The trainer also incorporates timing precision comparable to the prime system. This can be observed in the length of the computor runs, antenna slews, buzzer characteristics, and target tracking profiles. The prime system incorporates a legality check of the operator entered data to determine if the information is in acceptable form. Illegal entries are thus flagged to the operator via the data displays. The trainer emulates these legality checks, and down-grades illegal entries as errors and then notifies the instructor. The trainer maintains integrity of all switch and lamp emulation found on the Firefinder Radar. As an example, when a switch is pressed, the scenario gives a reaction to the student in the form of lit indicators, data prompts, and buzzer cues. Included in this switch emulation is incorporated a legality check similar to that previously mentioned for data entries. The scenarios were designed so the student is able to use the prime system technical manual throughout the exercises in order to become familiar with their format and content.

CAI/CMI

While accurate emulation of the operational characteristics of the prime system is important in the design of a simulator, enhancement of the simulation is needed for training purposes. An effective trainer is much more than just a good simulator. The approach used makes extensive use of computer assisted instruction (CAI) and computer managed instruction (CMI). The CAI inherent in the scenarios gives the student simulated supervisor messages and task directions at appropriate points in the exercise. As an example, after the student has correctly initialized the radar system, he is alerted with a buzzer cue and prompted with the message "Supervisor commands you to begin radiating". It is important to understand that an operator in the battlefield cannot engage this feature without direction from his supervisor. By the scenario prompting the student, the instructor is freed from the burden of cueing the student throughout the training lesson. CAI techniques are also used in branching the scenario processing backwards to reprompt a student with the original stimuli if the student's reaction was an error. Scenario CMI is evident in the many messages sent to the instructor's console when a student has made an error. Once the instructor has been made aware of the student's difficulties, he can intervene in scenario processing by freezing, back-sequencing, zeroing (restart at beginning), or aborting the exercise.

The summary area of the instructor's display is also enhanced by an inactivity alert for each student station. If the student fails to make a switch action within a specified period of time, the instructor is alerted that the student has become indecisive and is probably lost. In the same way if the student makes a number of consecutive errors which exceed a scenario specified threshold, then the processing will send a "Consecutive Error Alert" to the instructor station. Exercise grading allows some errors to be classified as critical. These are used to down-grade students who make switch actions which might harm the equipment or cause a safety hazard, if done on the prime system. These critical errors also appear in the instructor's notice field.

The detailed display area at the instructor's station typically lists all switch actions and data entries performed at a particular student station. This display is enhanced by scenario control of two of its fields. Stimuli messages show the instructor a summary of the training conditions being presented to the student. If a student has made an error, the expected action field informs the instructor what correct response should have been taken. Figure 8 illustrates the instructor's station console and the scenario enhanced fields of information. In order to assess a student's speed in performing a training task, scenario controlled clocks are utilized to determine the time interval between switch actions. If the student's time to perform a task is longer than that required by the training objective, his time criteria score is reduced, and a notice is generated in the instructor's detailed display. See figure 9 for a CAI/CMI feature summary.

Training Effectivess Tests

The approach taken to building an effective trainer was validated by a series of government conducted training effectiveness tests (TET). The TET was performed on the operational scenarios with 20 students over 10 days under a well-structured test environment. The tests covered exercises from initialization through the various hostile modes. The first important result of the tests is that the correct number of different versions were chosen for each exercise. During the design phase, it was decided that for remedial and reinforcement purposes 5 versions of the same exercise were necessary. Results of the TET showed that a learning plateau trend was exhibited at the 4th of 5 possible versions.

A high transfer of knowledge was displayed by the students who learned on the Firefinder Trainer Device versus the control students in the test. As an example, the test group performed the initialization task on the prime system an average of 32% faster than the control group with no appreciable difference in error rates. The more interactive exercises strengthened this learning trend in an even greater way. The test group performed the hostile mode tasks an average of 47% faster than the control group and at the same error rate.

A single Firefinder Trainer device has the

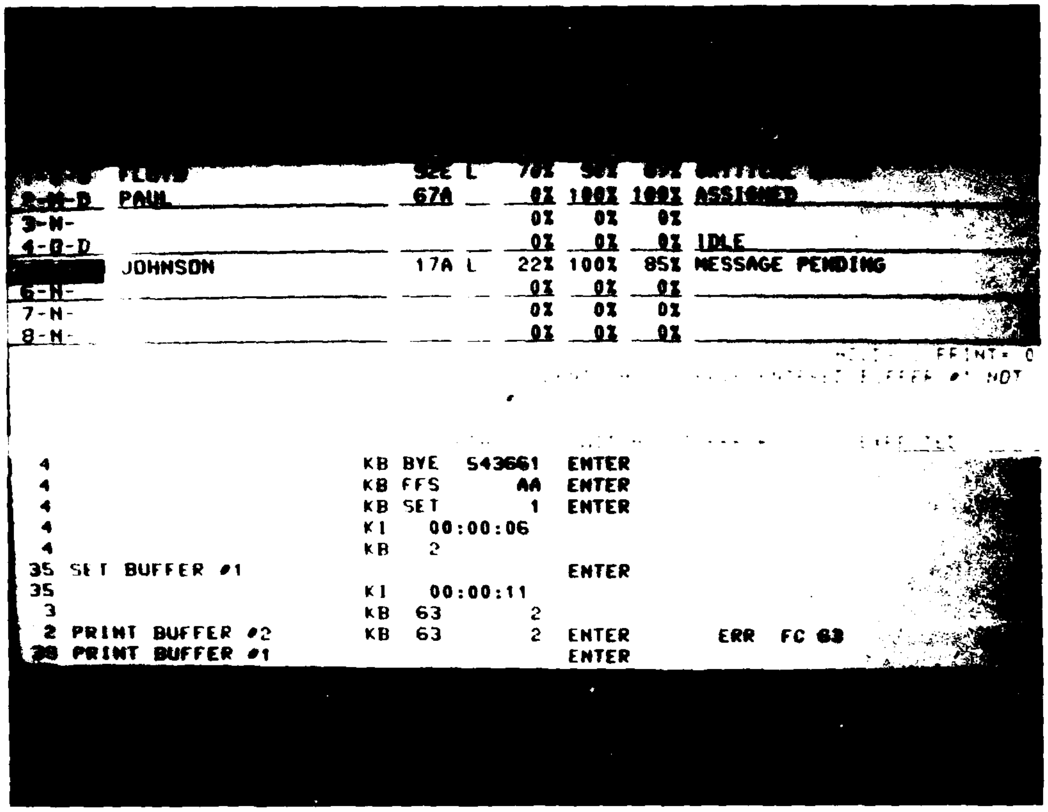


Figure 8. Instructor's Station Console Display

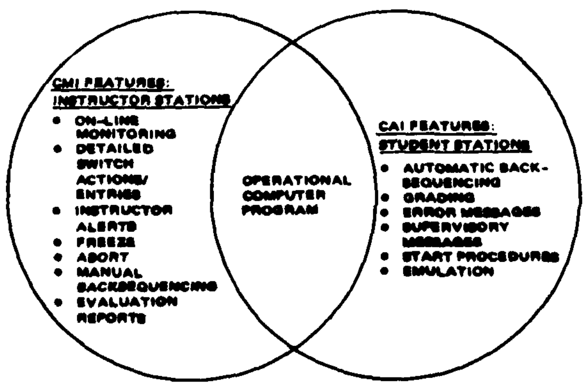


Figure 9. Dual Purpose Computer Instruction

capability of training 6 students with 2 instructors. Because of a logically arranged instructor station control format, one instructor can be allowed to monitor all 6 student stations. The TET raised the question, "Can effective training be conducted with a 1:6 ratio?" By comparing delays and performance results of 2 groups of students, it was found that students trained using the 1:6 ratio experienced as few or fewer delays and performed as well or better than the students taught at the 1:3 ratio.

Scenario Generating Program

The Scenario Generating Program is the primary support software package which provides the scenario creator with the capability to generate and modify scenario data. This program was designed to be used by inexperienced instructor personnel. Knowledge of programming languages and special skills is therefore not required. The Scenario Generating Program contains graphic representations of the locations of switches, circuit breakers, and indicators which relate to the actual equipment. Data to be entered is in logical terminology. For example, the scenario creator may want to illuminate or extinguish an indicator on the student station. This is accomplished by simply entering the word "ON" or "OFF" in the field next to the graphic representation of the specific indicator. Figure 10 illustrates these graphic representations.

Scenario Data Base Structure

An important factor which adds to the efficiency of the scenario data base generation is the reuseability of step elements. Before the reuseability concept is addressed, the hierarchial structure of a scenario must be covered.

One exercise contains a variable number of frames, with each frame containing a variable number of steps. Therefore, there is a three level structure inherent in scenario topography. Each of these elements (exercise, frame and step) is assigned a unique element number and is stored in a specific memory location. The scenario elements can be recalled and modified. Exercises can borrow frames or steps from another exercise, therefore, there is complete reuseability of elements at the lower two levels.

This technique reduces system storage requirement, because borrowed elements do not have to be stored twice. Savings are also realized using the pivot concept, because the scenario versions derived from the master only have to store new step elements, not the common ones. Figure 11 shows the savings realized by this reuseability design feature.

The importance of this design feature is that once a training objective is coded into a portion of a scenario, that portion can be lifted and incorporated into any other scenario that includes

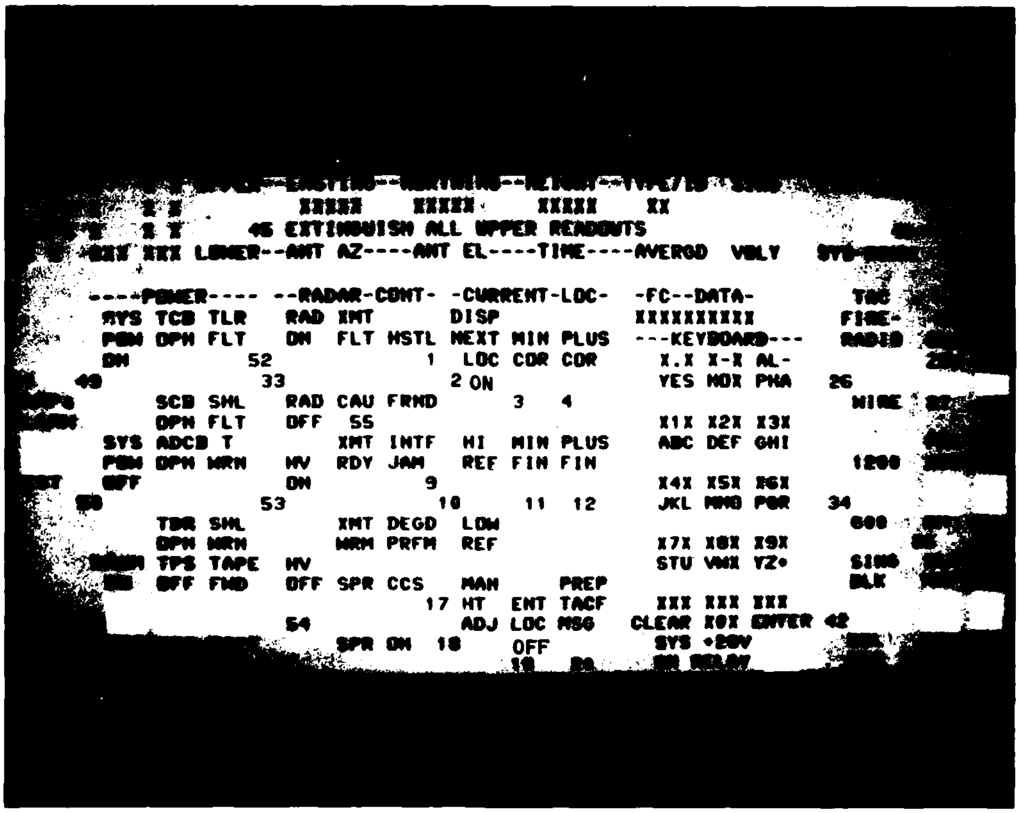


Figure 10. Scenario Generating Program Display

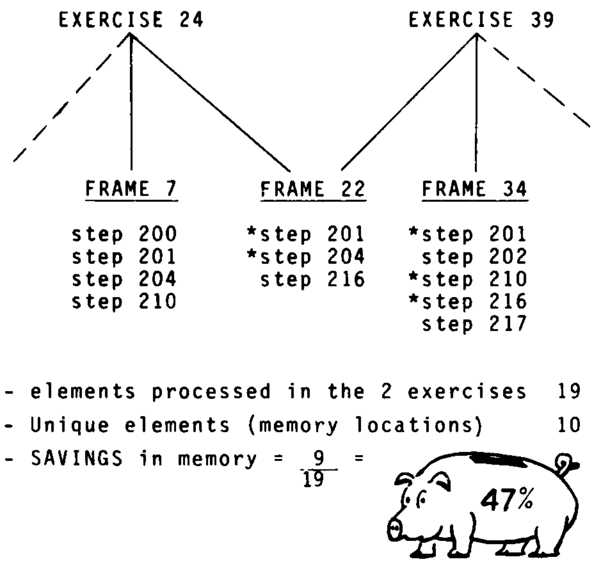


Figure 11. Savings Realized by Data Base Reuseability

the same training objective. As an example, one of the objectives of a beginning hostile scenario is to train the operator in the use of the TACFIRE prompts. A group of frames was generated to meet this objective. In the more advanced hostile scenarios, wherever the same objective was reiterated for training reinforcement, it was only necessary to copy the TACFIRE frames and integrate them into the other scenarios. In this way, the instructor personnel need not waste time reinventing the wheel as would have to be done with a more traditional software approach.

Configuration Management

The single most important tool in the management of scenario generation activities is the faithful adherence to configuration control guidelines. Because elements are assigned a unique element number, an indexing system is required to keep track of elements in use. The authoring language integral to the Firefinder trainer has this built in directory for accounting purposes. Program management requires visibility of the expansion potential of the data base. A configuration utility also exists which prints out all elements not in use.

Because elements are reuseable, many exercises might be affected by the modification of an element. A cross reference program has been developed to determine which higher level elements contain a particular lower level element. Before any modification of existing elements is performed, a cross reference is run to determine the total impact of the proposed change throughout the scenario data base.

During the generation of a scenario, the paper documentation listing is changed often. Configuration utility programs can print an entire exercise including all frames and steps in a logical sequence by sequence breakdown. This same utility can print all the steps of the data base in numerical fashion for program package delivery to the customer.

Maintenance Training

Organizational maintenance tasks taught by the trainer emphasize removing and replacing circuit cards. Card cage assemblies are represented by full sized photographic panels. Instead of removing and replacing the faulty card, the student enters a unique 3 character remove and replace (R&R) code which can be located on the photopanel above the card to be removed. (Refer to figure 12) The scenario can then grade the student's entry for correctness and eliminate the fault indications from the student's stimuli, if the R & R code entry is correct. The fault indications will remain if an incorrect card is exchanged.

In some cases the organizational maintenance technician needs to align a circuit card assembly using a potentiometer adjustment. For these cases, the trainer has provided the real pots and software emulation to simulate the normal system response to the pots being turned.

By customizing the maintenance trainer to simulate what is only needed for organizational level training, a cost-effective approach is realized. All hardware assemblies that were needed for particular training tasks were designed into the system. No extra expense was incurred by designing simulated circuit cards, which would never be needed for this level of maintenance training.

Trainer Diagnostics

To aid the instructors and trainer maintenance personnel in isolating hardware faults in the trainer, two diagnostic scenarios were provided. These scenarios perform an analysis on both the operator and maintenance portions of the student station and allow support personnel the ability to isolate faults down to the indicator, switch, or circuit card assembly. Using these diagnostic scenarios, the mean-time-to-repair of less than 30 minutes has been demonstrated.

Generic Simulation

An additional customer benefit is that the trainer has the generic ability to simulate other systems with a similar hardware configuration. By relabeling the switches on the present equipment panels, scenarios can be generated to train the student on tasks unrelated to the original design concept. As an example, a scenario to train operators for the Army's automated surveying system, "Positioning Azimuth Determining System" (PADS) was designed using the Firefinder student station. No software changes were needed, and therefore the cost for this scenario was very minimal. More elaborate training conversions are feasible by adding additional equipment panels and software support modules to the existing trainer. In this way, unrelated training environments can co-exist within the same trainer without the need for separate computers, instructor stations, or peripheral equipment.

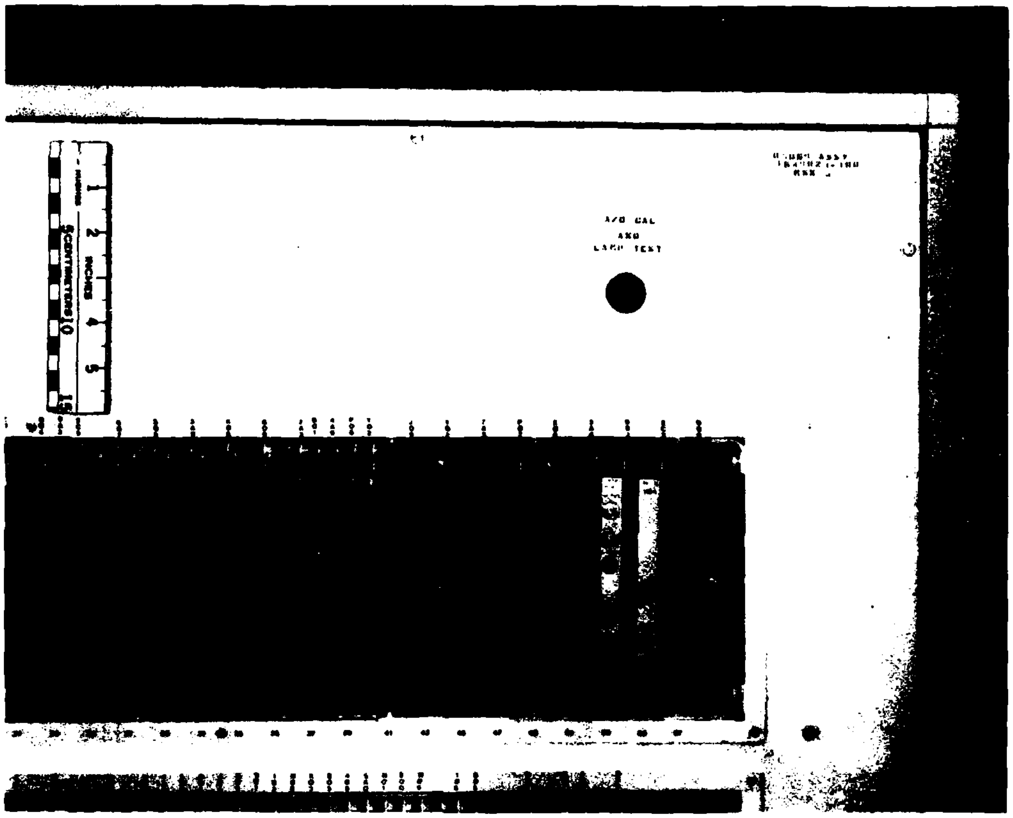

Figure 12. Remove and Replace Codes Found on Maintenance Assembly


## SUMMARY

The Firefinder Trainer incorporates a scenario data package which translates each of the training requirements into an interactive system between the student and the computer. The trainer is basically a simulator, which emulates each of the functions of the prime system with a high degree of fidelity. The scenarios then enhance this simulation through the use of CAI/CMI techniques to transform the system into an effective training device. This approach was validated by the training effectiveness tests conducted. The scenario data base is easily managed because of the various configuration utility programs provided. The Chief Programmer concept and the family breakdown maximize the scenario writing staff's efficiency in developing the training programs. The further breakdown of scenarios into 3 difficulty levels optimizes the interface between the student and the instructor. The features of the maintenance trainer allow the student to increase his proficiency in repairing the system to a very high degree. The Scenario Generator Program and design of the scenario forms allow the creators to develop a training package rapidly and in a cost-effective manner. In the same way, retro-fitting the trainer to incorporate changes in the prime system is simplified. These and other design features allow the customer to realize substantial savings throughout the life cycle of the device.



## ACKNOWLEDGEMENT

The authors wish to acknowledge the contributions of Major Robert White of PM-TRADE, Firefinder Training Devices Program Manager, in directing the development of the scenario data base concepts described in this paper.

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# AVOIDING THE PITFALLS IN MAINTENANCE SIMULATOR DESIGN

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## ABSTRACT

Simulators are now generally accepted and even sought to support maintenance training; especially troubleshooting. This paper deals with the problems that are encountered by relying solely on a task analysis for establishing simulator design specifications and how these problems can be avoided through the use of a functional engineering analysis of the prime equipment. It explains how a functional engineering analysis can alleviate the problems of determining how much front-end analysis is necessary for simulator design, aspects of the configuration, such as, three-dimensional versus two-dimensional simulators, and the depth of the cost analysis. The necessity of conducting a functional engineering analysis in order to prepare viable simulator design specifications is elaborated with an example. This necessarily leads to a description of the increasing role of a new breed of engineer in designing simulators for maintenance training.

## INTRODUCTION

In recent years, simulators for maintenance training have come into vogue. The argument now is not over their value and how well they perform compared to actual equipment trainers. Now the arguments are whether simulators should be three-dimensional, two-dimensional (i.e. level of physical fidelity), what types of display media should be used, what levels of functional fidelity are necessary, and there are attempts being made to establish and standardize procurement procedures. There is discussion and research regarding the extent of student cueing and tracking, and how simulators can support different cognitive styles. There is concern about user acceptance. And the problem being given the most attention is how much front-end analysis is necessary in order to establish and specify simulator design. The task analysis that occurs during an Instructional System Development process is generally thought to be adequate as a means to specify simulator design. We have found through the actual experience of building in excess of 500 simulations that a new concept must be applied in all maintenance simulator design; that is a functional engineering analysis. This in turn implies the need for a new breed of engineering talent in the training community.

## PROBLEMS/BACKGROUND

Obviously there are problems and questions to be answered, but pitfalls? "An unsuspected difficulty, danger, or error that one may fall into," according to Webster. With the many questions and unresolved problems regarding the design of maintenance training simulators there are obviously pitfalls. However, I refer here to an area of effort and investigation which has not as of yet received any great emphasis. And that is the lack of attention given the prime equipment during the Instructional System Development (ISD) effort. There is little to no regard given to a functional engineering analysis of the prime equipment as it relates to its own operation and how that may affect training or the specification and procurement of maintenance training simulators. (It is not my intention to debate the value of simulation devices for maintenance training, but for this discussion, to accept it as a viable training tool).

The pitfall occurs through a lack of the realization that the prime equipment must be characterized in its own right before a legitimate simulator specification can be prepared. This must be done by the procuring agency prior to RFP release or provided for in the solicitation as the first task to be undertaken by the successful bidder.

Too often maintenance simulators are viewed as being the baby brothers (or sisters) of flight simulators and therefore need not be designed with the considerations that go into flight simulator design. For example, the flight characteristics analysis is analogous to an engineering analysis of the hardware from a maintenance aspect.

The problems of designing, specifying and constructing maintenance training simulators may indeed be more difficult to handle than the problems affecting the design of flight simulators. The maintenance activity occurs within and without the prime item. In flight simulation there is at least the convenience of knowing that the student pilot's activity has a nice neat, well defined set of parameters all within the cockpit. In maintenance training, the activity parameter has the potential for being the entire aircraft, and similarly for whatever the prime item might be. If it's a radar, the maintenance simulation must contain both operator functions and intrusions into the device itself.

Capt. D.H. Westbrock, Commanding Officer of the Naval Training Equipment Center, writing in the December 6, 1979 issue of the NTEC Centerline recounts a meeting regarding acquisition and support issues prior to the first Interservice/Industry Training Equipment Conference in Orlando last November, between representatives of industry and the Service's training organizations. That meeting, "was held in an attempt to get some agreement on the problems facing our business and to explore possible actions for improvement. It is worthy to note that there was little to no disagreement on the problems nor the actions for improvement."

He recounts that the problem areas can be generally summarized as the lack of proper front-end analysis; lack of early open discussion with industry on requirements which result in proposals and contracts without a clear understanding of the requirement; contract performance, especially schedule adherence is basically unsatisfactory.

I would add to that list a specific aspect of front-end analysis. And that is the lack of consideration given to the prime equipment for which a proposed training program and/or a maintenance simulator is to be designed; especially the lack of attention given to the engineering design concept of the prime equipment.

It is a commonly held belief and is generally true that there is lack of proper front-end analysis. We as contractors often respond to RFP's and "bend metal" before we have or are given the opportunity to clearly identify the training objectives, or before it has been determined how the device will fit into a proposed or existing training system.

This problem can be tempered if we take a good look at what enables the design of a simulator and what does not. The training community believes that it answers the training simulator requirements with its task analysis. Indeed, the task analysis specifies, if done properly, what the maintenance training simulator should do. It does not provide specifications for how the simulator will do what it is expected to do. Just as in the design of a flight simulator, there is a considerable gap between specifying what the simulator must provide for a student and making it happen.

Generally, when most people speak of front-end analysis they are referring to an approach to course design which is commensurate with the INTERSERVICE PROCEDURES FOR INSTRUCTIONAL SYSTEM DEVELOPMENT (IPISD) or Instructional Systems Development (ISD) as it is typically known. These procedures spell out in great detail how to objectively determine the training requirements necessary to bring a person to some specified level of maintenance capability. They pay homage to the selection of training aids, usually presuming that there are off-the-shelf types of equipment available; namely closed circuit TV, video tape, audio visual materials of various sorts, programmed instruction materials, both CAI and programmed text and recently, *maintenance simulators*. However, there isn't a hard and fast, solid procedure given on which anyone can stake very much during the selection process. It requires a great deal of interpretation and subjectivity based on personal experience and notion as to what these training aids and devices will provide. When maintenance simulation is desired, there is even less direction given to simulator selection, that is, what fidelity, functional or actual, three-dimensional or two-dimensional, etc.

A task analysis as it relates to maintenance simulator design is somewhat incomplete. First, consider an existing piece of equipment that has already been fielded, where does the training analyst go for his information. Usually the tech manual. And everyone knows what he gets from that, usually outdated information because the system has been upgraded and/or the tech manual was written to reflect the first model of whatever is being analyzed. The training analyst is locked into using this material for his task analysis and he may or may not have the opportunity to use questionnaires or interviews to determine the actual work requirements.

If it is a prime item system under development, then there is constant change in whatever technical documentation is available and no chance for interviews and questionnaires.

In either case, the training analyst is already a bit short on specific detail regarding the job, let alone a simulator.

This isn't intended to shortchange or to downplay the need for a legitimate task analysis, but rather highlight some of the real problems that result from using that information for maintenance trainer simulation design.

Presume that a task analysis has been done and is a realistic and legitimate description of the job requirements. Even under such circumstances it is impossible, but not believed to be so by many, to design a simulator without actually going to the prime equipment and performing a functional engineering analysis. Fortunately, there is an awareness of this deficiency beginning to permeate the training community.

A recent RFP issued by the Air Force for "The Development of a General Purpose Trainer for Flight Simulator Troubleshooting Training"(1) used a task analysis to determine that troubleshooting was the primary activity required by maintenance technicians for two particular MOS ratings. Who would not agree and take as a normal course of events, the fact that any maintenance activity is for the ultimate objective of keeping something running or if it isn't running or not running right, fixing it and making it run as it should. In any case, when we consider the highest order objective of a maintenance technician, it's just that, keeping something running as it should and thus requires some form of diagnosis.

The very significant aspect of that RFP is that "experience has shown that troubleshooting requires an overall understanding of the system logic and the flow of control actions within the system." Also, "prior experimental studies have shown that top down learning of a complex system is an effective approach. This approach is consistent with the whole-part-whole concept of instruction. The student first learns the mission or goal of the device and the operation of each of the subsystems that are used to achieve that mission. Individual parts, then, are seen as contributors to the overall system objectives. The system and its operation is taught and understood at the macrolevel before the student is ever taught about individual system components." Continuing from the background given in that RFP. "Initial troubleshooting training can also be taught at the macrolevel, and students can learn to rapidly identify the major subsystems which may be in error for a given malfunction condition. Additional training may be given to provide a more detailed understanding of each subsystem. When training reaches the level of the smallest replaceable unit, it need go no further: Additional training would not be truly job related." It adds "component parts, then are always taught within the context of total system operation and not as isolated things unto themselves." It is about time that this type of thinking has begun to show itself in various procurements.

Here is a case where the instructional concept is being specifically included in the development of the training and also formulating the trainer/simulator design. The RFP also calls for a functional analysis of the prime equipment in order to achieve this. "A central feature required of the Troubleshooting Trainer is the description and presentation of the system to be maintained in terms of functional flow logic. That is, the system hardware is analyzed into a limited number of functional systems, each system having a specific goal to be achieved with respect to the total system operation. These functional systems are further subdivided into a limited number of subsystems so that the complete digital flight simulator system can be represented by a "logic tree" arrangement of subsystems to the level of detail required to provide the required training. The functional goal or objective of each subsystem is succinctly described, and these objectives are documented in terms of input-output relationships. This method of system description enhances the instructional capability of this trainer, and teaches system logic directly." This approach to maintenance simulator design will insure the acquisition of cost effective and training effective simulators.

"A series of training systems called the F-16 Simulated Aircraft Maintenance Trainers (SAMT), built by Honeywell for the General Dynamics Corporation, are being evaluated by the U.S. Air Force at Hill AFB, Odgen, Utah. There are ten different trainers in the series, each designed to simulate a specialized subsystem of the F-16." (2)

The RFP that solicited these training simulations was nothing like the one just referenced. It required an elaborate training system with a set of simulation panels, an instructor station Master Simulation Control Console providing data displays and inputs, setting the training situation, student communications, random access slide projectors, and the system computer. The RFP specification went to great length to specify the program constructs and formats.

One of the Simulation Panel Sets was required to simulate over 600 Tech Orders and some 800 malfunctions. This kind of thinking implies that the student must be exposed to every malfunction he will encounter on the job. What's he gonna do when he gets there -- take the simulator?

Pity the guy trying to build these without obtaining the information available only through a functional engineering analysis. No wonder critics of maintenance simulators say they are prone to failure and they cost too much. This sort of thing will confirm their criticisms. And now there is an Air Force DRFP looking for a similar set-up for the impending F-15 SAMT procurement.

This approach to simulator procurement *includes the operation of the instructional* process and presumes the instructional concept. It preempts any significant enhancements or constraints that may be obtained from a task analysis and thorough prime equipment analysis.

Because "simulators are now known" to affect positive training results, training is expected to be effectively enhanced by the use of the ultimate maintenance simulator without considering the ramification on cost and deliver.

The first RFP(1) referenced is rare in that it explicitly requires a functional analysis of the prime equipment. A functional analysis of the prime equipment is usually taken for granted if it's ever considered. There is not the attention paid to it that there is to the analysis of training objectives, job behavioral descriptions and so on. Why? As mentioned earlier, it is presumed to be understood and to be contained within the task analysis, or there is not one within the procuring agency qualified to do it, so it is ignored. But how can the simulator emulate something if what it is to emulate is not thoroughly defined.

To reiterate, there is a large gap between the ISD task analysis results and the actual building of a maintenance training simulator. Too many people within the training design and analysis community and in the training schools believe that with the completion of the task analysis, the simulation specification is complete. It is hardly started. At most it will provide information about what may be expected of the simulator.

Obviously, the point being made is that a functional engineering analysis of the prime equipment to be simulated must be carried out either formally or informally, if a viable simulator is to be constructed.

DISCUSSION-FUNCTIONAL ENGINEERING ANALYSIS

A functional engineering analysis of the prime equipment is an analysis of that equipment with respect to its operation, normal and malfunctioning as that operation pertains to the level of maintenance which is required by the specified maintenance activity and the training concept and methods intended to be employed. The level of maintenance generally being Organizational maintenance (O-level) or Intermediate maintenance (I-level). Where O-level involves line replaceable units and I-level involves component repair. The functional engineering analysis requires the engineering analyst to document the logical operation of the prime equipment in terms of its functions between and among its subsystems.

The task analysis can bound what it is the simulator will have to do, but until a functional analysis of the prime equipment is completed, it doesn't provide the means or all the decision making capability necessary to determine what the simulation device will contain.

In fact, the functional engineering analysis of the prime equipment will provide inputs to the task list. If the functional analysis is done correctly, it will determine every subassembly or component that can be replaced, repaired, adjusted, serviced, etc. at the given level of maintenance and prescribed level of simulation (O-Level and I-Level). The level of maintenance prescribes the level of access that must be available in the simulation for the potential user (the student). It sets up parameters for determining what level of intrusion into the prime equipment must be considered by the engineering analyst. In other words, it establishes the depth to which the technician can go in his maintenance activity. As a result of that, it will prescribe test equipment required and instrumentation on the prime equipment and test points that must be available to the student on the simulator. In doing this analysis then, the engineer must locate and determine all replaceable, repairable, adjustable, and serviceable components and subassemblys in the system, and how they affect one another.

The result of this analysis may not seem to be that much different from what the task analysis should describe. But the functional analysis is basically thing or equipment oriented whereas the task analysis is person or student oriented. And like it or not, if someone is going to design a maintenance training simulator then he has to be able to describe the simulator in terms of the thing to be simulated. The functional analysis will uncover every conceivable test point and its response (including visual inspections, auditory cues, instrumentations, etc.).

The engineering analyst, in his logical documentation, uncovers maintenance techniques, whether known or not by "panels of experts" or subject matter experts. This occurs when he describes the system in terms of sets of logical operating algorithms. It will describe all tests, test points or activities within and on the prime equipment that are necessary to perform any of the maintenance, and particularly the troubleshooting activities, and at the same time reflect the response of the prime equipment over time. (We recently completed the design and production of a number of maintenance simulations for a major transport aircraft. The functional engineering analysis provided the contractor with data that led to the redesign of his prime equipment, and also uncovered numerous discrepancies in the maintenance manuals necessitating a substantial document revision.)

When a functional engineering analysis is completed, a mathematically logical model can be written or programmed so that it accepts any legitimate input at any of the given input ports and provides the proper output at any selected output port during any legitimate operating condition, on a continuous, dynamic basis; including both abnormal responses during a simulated malfunction and normal conditions; and if desired, allow a normal system configuration to be degraded.

The functional engineering analysis provides the means to develop the core program. When this is completed, and is done appropriately, any of the training requirements can be added to the program. In other words, if a programmed model is developed with respect to the prime equipment for the simulation, then peripheral program can be added to that core program as required. This would include simulator operations necessary to satisfy the training approach; other capabilities such as monitoring student actions, cues, use of a CRT, printers, etc. It also provides for an easy upgrade of the simulation as modifications are made to the prime system. And most significantly, the display or presentation medium can be two-dimensional, three-dimensional, a TV screen, paper and pencil; whatever is cost effective and training effective.

The task analysis can be used to determine how much of all the particulars uncovered in the engineering analysis are necessary to be built into the simulation device for it to fit the prescribed training requirements. The training approach will govern how the presentations will be made, and if there is enough feedback and crosstalk between the simulation designer and the training analyst, a viable model can be developed which will enable the construction of a simulator which can satisfy the prescribed training methodology. However, there must be communication between the training analyst and the engineering analyst; better still if the training analyst is an engineer. What I'm saying is that it's time to recognize the necessity of bringing the engineering analyst directly into the mainstream of training analysis. Not "interdisciplinary communication" through a manufactured interface of forms, procedures, and processes, but actually part of the training community. In effect, create a new engineering job function.

If a program model accurately represents the simulation desired, whether it is a functional logic representation of the system, or actual component or black box test points, that simulation can be used in whatever way the training objectives require; even when a large system is broken down into so called part task trainers. The functional engineering analysis will determine how each subsystem (part task trainer) relates to the whole system. These part task trainers will be subsets of the major system components. If the prime equipment analysis is accurate, it will allow any type of simulation configuration.

However, for a simulator to be effective, there must be a sharing of the engineering constraints regarding the simulation itself, the prime equipment particulars and the training requirements. And the only way the simulation design can be effectively discussed is to provide enough time for the engineering analyst to thoroughly understand and specify the prime system requirements, and then interrelate with the training analyst. This is not now being overtly done.

Since there is seldom enough resource allocated or available to conduct a thorough front-end analysis, and since a functional engineering analysis is a necessity in building a simulator, it can be used as the stepping off point for a front-end analysis or to augment the front-end analysis. Without the functional engineering analysis whether formally prescribed or not, there is no way an objective cost analysis of a simulator design can be made.

To help make clear what a functional engineering analysis is, an example is provided.

## EXAMPLE

Consider a training requirement for the maintenance of the electrical system on a spark ignition engine. The training objectives might be as follows. (Understand that these are only for example and for the case of brevity, only highlighted). A spark ignition engine is used here as an example because it is hoped that it will be easily understood by most people. The higher order training objectives could appear something like this.

1) Perform prescribed routine preventive maintenance functions.

2) Perform functional checkout tests of the engine electrical system according to prescribed technical manual procedures to ensure that engine operation meets specified operating standards.

3) Perform repair functions as may be required as a result of the system failing functional checkout tests and/or other unscheduled (troubleshooting) maintenance as required. (Diagnose faults.)

The next order would include the following, or similar objectives:

1) Use the prescribed technical manual to follow procedures.

   a) Locate proper tables, schematics, etc. (be able to use tech manual as required to perform and meet job function requirements.)

2) Select and use proper and appropriate tools.

3) Select and properly use necessary and appropriate support test equipment.

4) Follow divisional maintenance procedures for prescribed maintenance activities.

5) Perform listed troubleshooting (or diagnostic) activities. For this example consider only the electrical system of this hypothetical engine. Malfunctions will be discussed later. (There are problems specifying troubleshooting activities to the same detail that procedures can be specified. Symptoms can be specified, but the same symptom can be caused by different component failures. Failures provide different symptoms at different points of intrusion into a system. Troubleshooting trees fix the diagnostic paths available and become overly cumbersome as simulation specifications.)

A listing of objectives, would also include such items as tracing wires using electrical schematic diagrams, using test equipment such as ohmmeter/voltmeter, ampmeter, oscilloscope, low voltage circuit testers, identification of parts, location of parts, etc.

By its nature the functional engineering analysis will include a malfunction analysis. The malfunction analysis is often catagorized as a separate activity. But in the process of specifying a maintenance simulator that is to be used for troubleshooting, it must occur within the functional engineering analysis in order to specify parameters for the simulation.

The task analysis would also state what malfunctions are repaired during the maintenance activity based on frequency of occurrence, criticality, information from the Logistics Support Analysis (LSA), and so forth. It would also estimate the difficulty of fault tracing based on practicing technician feedback. The functional engineering analysis would also use the LSA, but in its own right would identify all replaceable, repairable, serviceable, adjustable items. Because of its functional aspect, it would uncover causes and their effects; failed components and the malfunction symptom. The functional engineering analysis would provide the means to select malfunctions for simulation which affect a large portion of the system and hence, require more of the system to be investigated in order to determine the cause. In this way the student could thoroughly exercise the system, and the requirements for hundreds of malfunctions be eliminated.

Stating the malfunction symptom does not necessarily state its cause or reflect a grouping or classification of malfunction causes. For instance, our engine may have as one of its malfunctions "engine does not start". This could be caused by a myriad of problems. The major systems at fault could be the ignition, the fuel, the charging, or the cranking system. Then in each system, any separate component could be at fault, with each different failing component giving off various and different symptoms during the test and diagnostic phase. (See Table 2 for a sampling of malfunctions.)

Presume for this example that among the training aids and devices deemed necessary for the instruction there is a simulator requirement and the simulation need has been defined as the electrical system of this hypothetical engine for a respective MOS.

How is a simulator specified, and by whom, in order to have someone build it? The job task analysis or the training objectives specify what it should do. Right? Wrong! They specify what the student will do in training, on the simulator and hopefully, be able to do when he eventually gets to his job.

Here is where the functional engineering analysis becomes critical, but not at the point at which it should come into play. It should have been started much earlier, in conjunction with the task analysis portion of the ISD effort. Even if no simulator is contemplated, a functional engineering analysis is necessary if reasonable courseware is to be prepared.

The functional engineering analysis should be done to satisfy the level of maintenance prescribed for the simulator training applications, and the depth of intrusion during maintenance activity is defined by the job activity. The maintenance activity is predetermined in the LSA or in the engineering design concept, and states what kind of maintenance can be performed, how it can be performed, and provides a means for determining who will and can do it (the MOS); O-Level, or I-Level maintenance.

It is interesting to note that the Army's Skill Performance Aids (SPAS) concept requires an activity similar to the functional engineering analysis described here. The first step in the SPAS development process is the conduct of a front-end analysis which defines performance requirements through equipment analysis and functional analysis which in turn yields a total task list.

Continuing with the engine example, the benefits that can be derived from a functional engineering analysis will become clear. Once the level of maintenance is determined, the device intrusion is also specified. The engineering analyst can state explicitly the functional and logical interrelationship of the device at the component or subsystem level that is relevant to the level of maintenance. He needs to go one level deeper than the level of maintenance to analyze causes and effects. In our engine example, the task analysis has specified normal operation and malfunctions are inferred by the troubleshooting requirement. The engineering analysis now determines those parts of the device that must be assessed to determine normal operation and their appearance, both normal and abnormal. When the malfunctions are considered, the functional engineering analysis becomes even more critical. As mentioned earlier, the same symptom can be observed and yet be caused by various and different malfunctioning parts or components. Considering the malfunction symptom "the engine will not start." This could have many causes. (See Table 2.)

The engineering analysis breaks the prime equipment, the engine and in particular its electrical system, into its design subsystems; with this engine: the charging system, the ignition system, the cranking system, the fuel system, and the mechanical system. We are concerned here only with the electrical systems (charging, cranking, and ignition).

It provides data such as that shown in Table 1. The normal configuration would be described first with consideration being given to evaluating the system i.e. the test points, visual inspections, instrument probes, auditory signals and so forth that will be used. The functional engineering analysis must also state the relation of one subsystem to another and the effects of each one upon all others it affects.

This listing would continue in similar detail for each of the other systems and their components. The reason this analysis must go to the component level, or one deeper than the maintenance activity, is that when different components fail within the subsystem, they can produce different symptoms and different responses within the system. For example, no voltage from the alternator could be caused by the voltage regulator or the diodes within the alternator and the first noticeable operating symptom would be a discharged battery.

TABLE 1

SUBSYSTEM COMPONENTS

| Component/System | Conditions | Functions/Use |
|---|---|---|
| 1.0 Charging System | Normal | Maintains battery electrical charge |
| | Abnormal | Overcharges battery. Does not maintain charge. |
| 1.1.0 Alternator | Normal | Provides current to maintain battery charge; output varies with engine speed, controlled by Voltage Regulator. |
| | Abnormal<br>Open Field<br>Shorted Field<br>Open diodes<br>Brushes open<br>Stator shorted | No output or too high an output. |
| 1.1.1. Electrical Connections | Normal | Provides specified output. |
| Field<br>Battery (output)<br>Ground | Grounded<br>Open<br>Corroded | Too low or no output. |
| 1.2.0 Voltage Regulator | Normal | Controls voltage level supplied to battery by regulating alternator field voltage.<br>0 - 1200 engine RPM voltage output varies 0 - 14.2 V.<br>1200 - max RPM 14.2 V |
| | Abnormal<br>Field voltage:<br>too high<br>too low | Alternator overheats (may short-out).<br>Battery discharges. |
| 1.2.1 Electrical Connectors | Normal | No voltage from alternator. |
| | Abnormal | No voltage to battery. |

Additional information must be obtained regarding the prime equipment - the prime equipment response and how the response can be observed. For the hypothetical engine it would look like the following:

| Activity | Equipment Response | |
|---|---|---|
| Crank Engine | Engine can crank: | normal |
| | | slow |
| | | intermittent |
| | | not at all |

The response can be observed on an auditory basis, or with a low scale tachometer, and a determination made as to how the simulator will provide that response.

| Activity | Equipment Response |
|---|---|
| Test alternator output | None on engine - Ampmeter, VOM, or Generator Output tester needed. |

The response can be observed on the face of the test instrument with the instrument set-up in a prescribed manner. The set-up must be specified.

Next needed are the malfunctions that are to be simulated. These can be overlayed onto the normal operating conditions during programming. With a functional engineering analysis it can be determined which malfunctions affect the greatest part of the system and coupled with a frequency of occurrence analysis and criticality those that provide the most training benefit can be selected. (An example of what happens when this is not done is a D.O.D specification calling for 623 malfunctions.)

Table 2 is a sampling of an adequate list of malfunctions which will provide training in using the test equipment and practice diagnosing the charging and cranking systems of this hypothetical engine.

For each item in the malfunction list there will of necessity be additional information provided. At some point the effect of each fault on all systems being represented in the simulation must be stated. Not shown in the table, but a very real situation is the compound malfunction, and where the symptom is placed for use on the simulator. Consider malfunction number 13, its symptom could have been "engine will not start" with the same fault and remedy as listed. In this case, the battery would be discharged and not able to crank the engine because the alternator is not able to charge the battery. Symptom number 13 relates to the subsystem -- the alternator.

If the alternator in the charging system fails (malfunction number 12) and the battery is fully charged, the engine could still be started but only a certain number of times - until the battery was discharged to the point where it could no longer supply enough power to the cranking motor to turn the engine, but the engine could continue to run because less power is required to keep the engine running than is required to crank it for starting.

The engineering analysis would determine how long the engine could run at various speeds after one start on a fully charged battery, and after being started, run, stopped and started again until the battery was discharged. This could be detailed with a set of algorithms:

TABLE 2

MALFUNCTION LIST

| | SYMPTOM | FAULT | REMEDY |
|---|---|---|---|
| 1. | Engine will not start | Dirty positive battery post connection (looks dirty) | Clean and tighten battery post connection. |
| 2. | Engine will not start | Discharged battery (most cells have low specific gravity) | Replace battery. |
| 3. | Engine will not start | Faulty ignition switch (open starter terminal) | Replace ignition switch. |
| 4. | Engine will not start | Faulty solenoid (open windings) | Replace solenoid. |
| 5. | Engine will not start | Badly pitted solenoid disc (open) | Replace disc. |
| 6. | Sometimes the engine cranks slow and is hard to start | Pitted solenoid disc (high resistance) | Replace disc. |
| 7. | Engine is hard to start | High resistance in positive battery cable (not visible) | Replace battery cable. |
| 8. | Engine will not start | Faulty battery cable, loose connection at starter | Clean and tighten battery cable connector. |
| 9. | Sometimes the engine cranks slow and is hard to start | Starter motor amperage draw too high (high resistance in windings) | Replace starter motor. |
| 10. | Sometimes the engine cranks slow and is hard to start | Poor connection between negative battery cable and engine block | Clean and tighten connection. |
| 11. | Engine cranks slow and is hard to start | Faulty regulator (voltage regulator needs adjustment) | Adjust regulator. |
| 12. | No charging action | Faulty alternator (brush broken) | Replace alternator. |
| 13. | Sometimes the engine cranks slow and is hard to start (Battery voltage low) | Faulty alternator (burned out diodes) | Replace alternator. |

Run time = (state of charge - previous run time x running charge loss rate)

- (no. of previous starts x start charge loss)

State of charge = available amps

Running charge loss rate = Amps loss x Engine RPM

*Start charge loss = X amps per start*

These algorithms would obviously have to be more specific and quantified. Once that is done though, they can easily be programmed.

The functional engineering analysis can be used as a tool to determine the simulator structure by providing a detailed listing of the prime equipment responses. These can in turn be used to aid a cost trade-off analysis during the design phase. For example:

Equipment Response -
Engine cranks: at normal speed intermittently

Observation -
Auditory

The simulator can be provided with a synthesizer to produce the sound or a written message describing the interpretation of the sound. Meter readings can be shown on simulated meters, a graphics display, a slide visual, or a written message.

Without a functional engineering analysis, there is no other source that will provide accurate descriptions of what is to be simulated.

As far as a three-dimensional simulator *structure is concerned, the functional engineering* analysis provides hard data that can be used to avoid falling into the trap of specifying a three-dimensional device. Presuming the simulator in question is going to be used as a means to acquire troubleshooting skills, and not necessarily motor skills, then simulating *the prime equipment responses* with a three-dimensional device would require an actual equipment trainer (AET) (and no simulator), and poor troubleshooting practice. If a mix of two-dimensional/three-dimensional components is required, determining what dimensional combinations are feasible can only be done with data obtained from an engineering analysis.

## SUMMARY

The functional engineering analysis provides the intimate knowledge of the prime equipment necessary to construct an effective, affordable maintenance training simulator. With data available from a functional engineering analysis, decisions can be made on how much functional fidelity is necessary or is worth providing. An example was given of an engine with a good battery, an inoperative alternator and the resultant variable run and start combinations. The cost in analysis and subsequent programming must be traded-off against the training benefit that would result from incorporating that kind of fidelity. The *same concept could be provided to the student* by judicious selection of malfunctions or programmed exercises which highlight that concept.

Conducting an effective *functional* engineering analysis for a maintenance training simulator requires a person with rare talents; an engineer who uses his engineering and technical experience and expertise as an engineer and as a training analyst. He must act in both capacities at the *same time. He must* extrapolate *from a prime equipment* what is *necessary* to produce a viable training device.

A functional engineering analysis [illegible] answer the questions of what kind of stu[illegible] cueing is required in a simulator or how best to accommodate cognitive styles, etc. but it will provide a solid data base for establishing the operational characteristics of a simulator for maintenance training. It will provide the data necessary for a contractor to accurately define his costs. And it enables realistic schedules to be developed and adhered to.

## REFERENCES


(1) "The Development of a General Purpose Trainer for Flight Simulator Troubleshooting Training", July 16, 1979, RFP No. E 33615-80-C-0012, pages 6 & 7, Section F.

(2) "Simulation For Maintenance Training", *Aviation, July/August, 1979, page 47.*


## ABOUT THE AUTHOR


Mr. Siecko is a Vice President of Educa*tional Computer Corporation (ECC) and head of* Instructional Systems Development. He is responsible for developing training design requirements for the company's EC II and EC 3 simulation models and all courseware products. He is co-holder of the patent for the design of the company's EC II simulator and was responsible for establishing the training concepts now implemented by the company. He directed the development and operation of ECC's federally sponsored demonstration manpower training project.

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LT-2 MAINTENANCE PROCEDURE TRAINER, F-16 AIS

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ABSTRACT

As Automatic Test Equipment (ATE) for Avionics becomes increasingly costly it becomes prohibitive to provide enough test stations to allow adequate individual hands-on training for maintenance personnel. The LT-2 Trainer for F-16 Aircraft Immediate Shop (AIS) helps alleviate this problem. The LT-2 trainer consists of a mini-computer system identical to that of the full F-16 AIS stations without the actual stimulus and measurement hardware. The trainer is thus about one tenth of the cost and complexity of the full test station. An Innovative Software Package allows test data captured on a full test station to be played back on the trainer. This provides the student with a realistic simulation of actual test runs. All the keyboard inputs and CRT responses are identical to those of a full test station. A Library of test programs and captured data sets allows both test station Maintenance Programs and Avionics Test Programs to be simulated. The captured data sets can be for good or faulty test runs. Faults can also be inserted into good data sets to artificially create simulated test failures. The techniques used on the LT-2 trainer allow cost-effective individual hands-on training for complex ATE.

BACKGROUND

The LT-2 Maintenance Trainer concept was developed by General Dynamics Electronics to provide a low-cost trainer/simulator for the F-16 Aircraft Intermediate Shop (AIS) Automatic Test Equipment (ATE). The F-16 AIS consists of four independent automatic test stations. A typical station is shown in Figure 1 with the control system components common to all four types indicated with numbers. Each of these test stations is designed to test a specific group of F-16 Line Replaceable Units (LRUs). The four test stations and their associated primary LRU testing areas are as follows:

1. Test Station – Flight Control Computer, Fire Control Computer, Inertial Navigation System.

2. Displays/Indicator Test Station – Heads-Up Display and Radar and Navigation Indicators.

3. Processors/Pneumatics Test Station – Air Data Computer, Radar Computer, Radar Digital Signal Processor.

4. Radio Frequency Test Station – Radar and ILS.

The F-16 AIS test stations are considered third generation automatic test equipment. Tests are controlled by stored programs written in the ATLAS test language. Common Stimulus and Measurement functions are provided in the Stimulus Unit and Measurement Subsystem (SUMSS). Peculiar stimulus and measurement functions are provided in Tester Replaceable Units (TRUs). Previous generations of ATE consisted entirely of rack and stack TRUs.

| INDEX NO | DESCRIPTION |
|---|---|
| 1 | COMPUTER, HP 21 |
| 2 | DISC DRIVE, HP 7905A |
| 3 | DISC CONTROLLER, HP 13037A |
| 4 | I/O EXTENDER, HP 12979A |
| 5 | STATION PRINTER, HP 9866A |
| 6 | STATION CONTROL PANEL, 2113100-001 |
| 7 | CRT/KEYBOARD, BEEHIVE B500-4000-0010 |

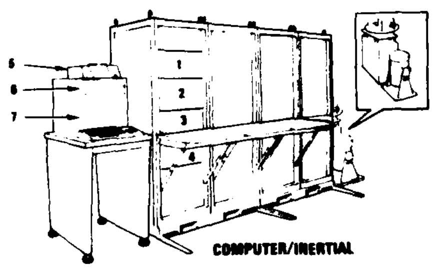


Figure 1. F-16 AIS Test Station

The USAF initially approached maintenance and operations training on the F-16 AIS using the classic method of instruction: that is, the use of an instructor in front of a class teaching from adapted engineering data, followed up by limited hands-on exposure to the actual equipment. This approach was later augmented through the use of video taped presentations. Students are taught the theory of operation of both the test stations and LRUs.

The usual constraints were and are operational: limited time and money, limited availability of test stations and LRUs, limited data, and changing design. There is very little time for extensive hands-on training. There is practically no exposure to faulted or faulty equipment. Consequently, the student sees or experiences only the results of testing operational equipment. When exposed to non-operational conditions, he is not permitted to find the fault, but is relegated to over-the-shoulder observation of the trouble shooting procedure. The methods used dictate a heavy reliance on downstream on-the-job training to achieve proficiency. The result of the training is that the student can perform only the rudimentary operations of LRU testing and ATE self-test. The limited exposure to the physical equipment permits the student to Remove and Replace (R&R) components from either the test station or LRU when directed by software controlled messages but he is not prepared for extensive trouble shooting.

## TRAINER REQUIREMENTS

In mid-1978, the USAF suggested that an AIS trainer could be a viable approach to solving some of their training problems. The conceptual design process, which ultimately resulted in the LT-2 F-16 AIS Trainer, proceeded along these lines. Since the F-16 AIS is a software intensive system, provisions for training the student in the operational commands and the use of the various built-in software troubleshooting tools must be made. The trainer would have to permit the student to have some control over his hands-on training experience such that he could repeat specific training exercises or phases if needed or desired. It would have to address the typical three levels of training associated with any ATE training program:

1. *Operational training*

   a. Operate ATE (Self Test Mode)

   b. Operate the ATE (LRU or Interface Test Adapter (ITA) Test Mode)

2. *Removal and Replacement* of faulty components when directed by software controlled messages.

   a. ATE
   b. LRU/ITA

3. Identification and isolation of faults not handled by automatic fault isolation.

A USAF concern throughout the early phases of the F-16 AIS program was the maintenance of the Computer Subsystem. This concern dictated that the trainer have the capability to train students in the care and feeding of the computer and its peripherals. The USAF wanted a trainer which used the actual software resident on the test station and the actual software which is used to test the LRUs, or at least as realistic a representation of the effects of that software as possible. They also expressed the desire to have capability for a large number of insertable faults, large enough so that it would be improbable that succeeding student classes could "memorize" the available fault exercises. Realism in the trainer control hardware was also desired, i.e., operational keyboard/CRT and station control panel. The USAF also wanted to achieve the "ideal" training scenario of having the student operate the "ATE" within the first day of training. Finally, the trainer must provide a way of giving the student maximum hands-on exposure at a cost far less than that associated with providing a full AIS station for each student.

A fortunate coincidence of hardware and software design in the F-16 AIS provided the means to achieve most of the requested trainer requirements by utilizing the control system hardware from the AIS and specially developed software to simulate the remainder of the AIS test station. This is the LT-2 trainer concept.

## LEVELS OF TRAINING

### Level One Training

All AIS test stations utilize the same control system which consists of an HP 21MX computer and associated peripherals including a disc drive, CRT, keyboard thermal printer, and a station control panel. During actual AIS station operation, the operator inserts a disc containing the LRU or self-test program, connects the LRU (if applicable) and via the keyboard and station control panel, directs the stored LRU or self-test program. Test results and operator messages are received on the CRT, station control panel and a thermal printer. The student can experience all of these level one operational exercises on the LT-2 trainer with the exception of physically connecting the LRU.

### Level Two Training

The level two training (removal and replacement of faulty components as directed by software controlled messages) can be fully experienced only for the computer subsystem. For the balance of AIS test hardware and for LRU failures, all of the operator controls and messages can be realistically experienced up to the point of actually replacing the faulty hardware. The limitation is a physical one, since the trainer as now configured is a 2D+ trainer; that is, the student/machine interaction is limited to the CRT display and keyboard and the station control panel. The (+) indicates that for the Computer Subsystem there is full three-dimensional training capability.

### Level Three Training

Identification and isolation of faults not properly identified by the AIS self-test or LRU diagnostic software can be simulated on the trainer and all the available software troubleshooting tools and techniques can be taught with the limitation again of not being able to physically handle the faulty hardware. In this case, an instructor would evaluate the suitability of the student's approach to such a problem and the student's analysis of the data available from the troubleshooting tools. The trainer software can then be directed to yield a good or faulty test result on the next pass, indicating the success of failure of the diagnosis and proposed corrective action.

## SYSTEM AND SOFTWARE DESIGN

### Common Control Bus

The AIS test station computer controls all stimulus and measurement hardware via a common control bus. The computer acts as the bus controller, sending digitally coded commands to and requesting data from all of the addressable hardware modules connected to the bus.

When a test is in progress on an AIS test station, all digital control data is transferred between the computer and the test hardware over this data bus system. The station control software generates the data output to the hardware and reacts to the data input from the hardware and to operator commands. The control software, in turn, drives the operator displays on the station control panel and CRT. The LT-2 system software stores the digital data input from the hardware into a disc file during ATLAS test program execution on an AIS station. This data is read back on a trainer and substituted for the data input from the actual hardware. In this way the LT-2 software can simulate the operation of a complete test station on a trainer station that only contains a computer, disc system and station operator console.

### Operator Modes

The trainer software operates in either the data capture or data playback mode on an AIS test station and in the data playback mode only on the trainer station. In the data capture mode, the I/O routines store only the digital data input from the hardware in a "captured data" disc file. The data output to the hardware (control words) are not needed for playback.

The data capture operation is performed by executing an ATLAS test program on a full F-16 test station with an LRU or self-test adaptor connected. During data capture, all input digital data is stored in a disc file for retrieval in the data playback mode. Once the data has been captured for a particular ATLAS test program, that program can be executed in the data playback mode on the trainer station. In the data playback mode, the I/O routines read the captured data from the disc file instead of inputting the data from the hardware. This process causes the control software to react precisely as though the test hardware were present. All station control console displays and operator controls react the same as they did during the data capture test run on the AIS test station.

The data capture/data playback technique can be implemented on any computer controlled test system that has a similar data bus interface and common I/O routines which service the bus.

### Simulating Hardware Failures

Once the data capture/data playback approach had been proven, it was found that either test station hardware failures or LRU hardware failures could be simulated by modifying the digital data which is input from the test station hardware. This failure simulation capability is implemented using a fault insertion table. This table allows the user (instructor) to modify any data word read in from the station test hardware, thus providing an almost unlimited fault insertion capability. Each fault insertion table entry contains the ATLAS statement number at which the data modification is to occur, the data hardware control bus address and the new data (in octal) along with a data mask which indicates which bits are to be modified.

Failures can be simulated in either the data capture or data playback mode of operation. In the data capture mode, the digital data is modified as it is read from the hardware and before it is stored in the captured data file. In the data playback mode, the digital data is modified as it is read from the captured data file, but the captured data file is not modified.

There are some restrictions on simulated failures. The simulated failures force the ATLAS test program through a specific predetermined path. In the data capture mode, the user (instructor) must insure that all subsequent failures down the selected path are consistent with the original simulated failure in order to produce a realistic hardware failure simulation. When simulating a failure in the data playback mode, the user (instructor) must be sure the inserted fault does not force the ATLAS test program down a path which requires additional hardware data not present in the stored data file.

### Program Branches

When an ATLAS test program contains a number of program paths that can be selected by the student during program execution, retrieving the proper captured data for the selected path can present a problem. We solved this data retrieval problem using a branch table. This table contains the first statement number of every program branch to be executed and the disc file location (sector, word) of the data captured for that program branch. The branch table is created by the user (instructor) and the file locations are filled in by the trainer software. Before executing the ATLAS test program in the data capture mode, the user (instructor) must enter the first statement number of all program branches for which he intends to capture data. During program execution, the trainer software determines if the next statement to be executed is the beginning of a new branch by comparing it with the statement numbers in the branch table. If the next statement is the beginning of a new branch, the trainer software stores the captured data file location (sector, word) with that statement number. The trainer software can now locate and retrieve the captured data for each program branch when running in the data playback mode.

## Lesson Plans

A library of captured data sets can be created for LRU test, station self-test, and station alignment programs to provide comprehensive training for the student. Generally, one good test run and a number of faulted test runs are collected. The faulted runs can be created by modifying the input data using the fault insertion table or by collecting data sets running with bad LRUs or faulty station hardware. Using the trainer software, a technician can capture additional data sets in the field. Problems encountered in the field can be captured on disc and sent back to the training facility. This capability can act as a constant feedback loop to insure that actual field problems are used to train new maintenance personnel. Maintenance history will provide good LRU candidates for data capture test cases.

The instructor can build lesson plan scenarios from the library of captured data sets. A number of test cases can be presented for each LRU or station hardware device. A student workbook can also be provided to guide the student to the proper diagnosis of hardware problems. The lesson plan table stored on the disc by the instructor controls the selection of the data set to ' e used for each program executed by the student or for each iteration of the same program. Fairly complex lesson plan scenarios can be stored, requiring the student to execute a particular sequence of diagnostic programs to locate a fault before his main test program will run with successful results.

## Troubleshooting Tools

A number of trouble shooting tools included in the AIS software can be utilized on the LT-2 trainer to assist in level three training. One such tool allows the student to monitor via the CRT or printer all of the data passing over the control bus during the execution of a program. Proper analysis of this data can assist in pinpointing faults which the test programs do not isolate.

## APPLICABILITY

The concept of the LT-2 trainer design is to use minimum hardware and sophisticated software to permit the student to experience the effects of actual test runs on full AIS stations with all the proper operator machine interactions. This concept may be applicable to a significant range of other trainers for automatic test equipment and for other automated military or industrial equipment. In order for this approach to be useful, the system would have to satisfy most of the following criteria:

1. Computer controlled-automated system

2. Software intensive – relies heavily on software for operator interfaces

3. Common data bus – system hardware commands and data travel across a single party line type data bus

4. Common I/O driver routines – all communications to hardware are via the same software I/O subroutine

5. Data storage available – sufficient data storage capability must be available to store all I/O data for a full test run, mission, etc.

6. Limited program branches – the operator selected program branches must be limited to a reasonable number, such that it is feasible to capture and store data for each branch

7. Non-critical execution times – program execution time in the data capture and simulate mode may differ from the normal execution times of the programs due to the storage and retrieval times for the data

8. Operator training priority – the operator control and analysis functions, rather than hardware handling, must be the primary purpose of the training.

## CONCLUSION

The LT-2 trainer concept, aside from its rather minor limitations, does provide a cost-effective way to achieve an adequate hands-on training environment for complex ATE. Its limitations, primarily in the area of the handling of physical hardware can be overcome with a minimal amount of supplementary training on a full AIS station.

The unique concepts of the LT-2 trainer could be easily extended to trainers for other systems which satisfy the listed criteria for applicability.

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E-3A MAINTENANCE PROCEDURE SIMULATORS - A NEW BREED OF CATs

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ABSTRACT

Computer-Aided Trainers (CATs) for mission avionics subsystems on the E-3A "Sentry" aircraft simulate BITE outputs to support self-paced practice in flight line maintenance procedures. They represent a new breed of CATs evolved through application of the Instructional System Development (ISD) process and a unique synthesis of hardware, software and "courseware" to satisfy organizational maintenance training requirements. This paper is in two parts. Part I summarizes the application of the ISD process used to identify requirements for training and training equipment. Part II concentrates on the evolution of the maintenance trainers, emphasizing the system development using as a case study the E-3A Maintenance Procedure Simulator (MPS) for the AN/ASN-118 Navigation Computer System.

PART I: SUMMARY OF ISD APPLICATION

Selection of CATs as the most cost effective method for satisfying E-3A training was strongly influenced by results of a 1974-76 effort to define training equipment requirements for four major groups of E-3A mission avionics equipment prior to delivery of the first aircraft in March 1977. Table 1 lists these four equipment groups and the specialty codes and titles for the four types of technicians who must be trained to maintain them.

Scope of ISD Effort

When properly applied, a joint contractor/government ISD effort can provide a system acquisition program director with essential information needed to define a cost-effective "mix" of classroom, laboratory and on-job training. The E-3A Sentry Engineering Division (YWE) may be unique, in that since the inception of the Airborne Warning and Control System (AWACS) program, a separate section has been responsible for all human factors, training, and training equipment, with contract technical support from the American Institutes for Research (AIR), a nonprofit firm specializing in applied education and training research. In the E-3A program, collaboration between contractors and government personnel in the ISD process was achieved by a series of working-level Technical Interchange (TI) meetings during the 18-month period from September 1974 through January 1976. A study contract to develop specifications for training equipment was initiated by Boeing, the E-3A prime contractor, in December 1974.

Inputs available to the government/contractor ISD team included:

- o Draft Training Plan
- o Qualitative/Quantitative Personnel Requirements Information (QQ PRI)
- o Aerospace Ground Equipment (AGE) Plan
- o Optimum Repair Level Analysis (ORLA) Reports
- o Reliability/Maintainability Allocations, Analysis and Assessment Reports

TABLE 1. AWACS MISSION AVIONICS EQUIPMENT

| AWACS MISSION AVIONICS EQUIPMENT | AFSC | AIR FORCE SPECIALTY TITLE |
|---|---|---|
| Data Processing | 305X4 | Electronic Computer Systems Repairman |
| Communications | 328X0 | Avionic Communications Specialist |
| Surveillance Radar | 328X2 | Airborne Early Warning Radar Specialist |
| Navigation/Guidance | 328X4 | Avionic Inertial and Radar Navigation Systems Specialist |

Figure 1 shows a functional flow diagram of the training equipment requirements analysis based on the procedures defined in AFP 50-58 "Handbook for Designers of Instructional Systems." Representatives of Air Training Command (ATC), Tactical Air Command (TAC), E-3A SPO personnel and AIR participated in TI meetings with Boeing training specialists during the ISD effort, which was divided into six phases:

(1) Review AWACS equipment and AGE to establish maintenance task descriptions.

(2) Determine job performance and knowledge requirements for each Air Force Specialty Code.

(3) Establish maintenance training objectives for each Air Force Specialty Code.

(4) Determine training media requirements to accomplish training objectives.

(5) Define candidate training equipment configurations needed to satisfy media requirements.

(6) Develop detailed specifications for preferred training equipment configuration selected for each Air Force Specialty Code.

The outputs of the ISD study effort included a comprehensive technical data package containing the "Training Equipment Preliminary Requirements Report" and a set of draft specifications and a set of budgetary cost estimates. The methods used to define the training equipment are described below, using the AN/ASN-118 as an example.

## Maintenance Task Analysis

Using the procedures defined in Volume II of AFP 50-58 as a guide, maintenance tasks were analyzed independently by ATC representatives and the prime contractor. The team analyzed the organizational maintenance tasks defined explicitly or implicitly in the QQPRI and AGE Plan. The Boeing team analyzed intermediate (shop) maintenance tasks resulting from the ongoing ORLA and R/M analyses. Results were consolidated on standard ATC task description worksheets to produce a common baseline for definition of learning objectives.

## Definition Of Learning Objectives

Formal learning objectives for each class of related tasks (e.g. flight-line checkout procedures) were first defined independently by ATC and Boeing, then consolidated on a set of Learning Objective Worksheets (LOWs) developed by AIR for this purpose. Each LOW identified the learning objective, the standard for its measurement and the analyst's judgement regarding the best learning media to support the achievement of the objective. Differences in media recommendations were resolved at TI meetings. As a timely byproduct, the scope and content of ATC Course Training Standards for resident training courses, field training at TAC bases, and Type I cadre training at contractor and subcontractor facilities were also established at these TI meetings.

## Evaluation Of Training Configurations

For each E-3A mission avionics system, two or more "candidate" training equipment configurations were identified and rated on 26 different characteristics grouped in four categories as illustrated in Figure 2. Candidates generally represented the extremes of full simulation and actual operational equipment, with some mixed cases combining computer-assisted instruction (CAI) with mockups and actual operational end-items. Thus, for the AN/ASN-118 system, Candidate A was defined as an Actual Equipment Trainer with three student stations; Candidate B was a Computer-Aided Training System using two student CRT terminals to guide students in the operation of front panel mockups; Candidate C was a mixed system combining features of the first two configurations.

Tasks assigned to Categories 1 and 2 were classified into the seven types used by the USAF Human Resources Laboratory for development research on Job Performance Tests for electronic technicians. For the third category of Training Suitability, each candidate was evaluated against qualitative criteria determined by a training literature review to yield high training effectiveness. The extent to which each candidate would minimize support requirements was rated in terms of the impact on facilities, computer programming support, unique test equipment, and overall ease of maintenance.

For each of the 26 traits shown at the left in Figure 2, analysts entered a rating taken from the following five-point scale:

| Rating Description | Rating |
|---|---|
| Little or no capability | 1 |
| Partially satisfies criteria | 2 |
| Satisfies most criteria acceptably | 3 |
| Satisfies all criteria acceptably | 4 |
| Satisfies all criteria exceptionally | 5 |

The weighting factors shown in Figure 2 were based on a three-point scales (low/moderate/high) for rating the task proficiency training suitability, and the impact on support requirements. The products of each weight and candidate rating were entered in the "adjusted" column, then divided by the number of criterion items to obtain a "normalized" rating between 1 and 5 for each major category. Regrettably, the procedure used did not include multiple raters or inter-rater reliability measures. As indicated in Figure 2, the Computer-Aided Training system (Candidate B) was rated highest, and was therefore recommended to support training of 328X4 personnel in maintenance of the AN/ASN-118 system.

The E-3A prime contractor's draft report detailing the ratings and rationales for each of the four recommended training equipment configurations was reviewed at a TI meeting in September 1975. Results were curious and disappointing

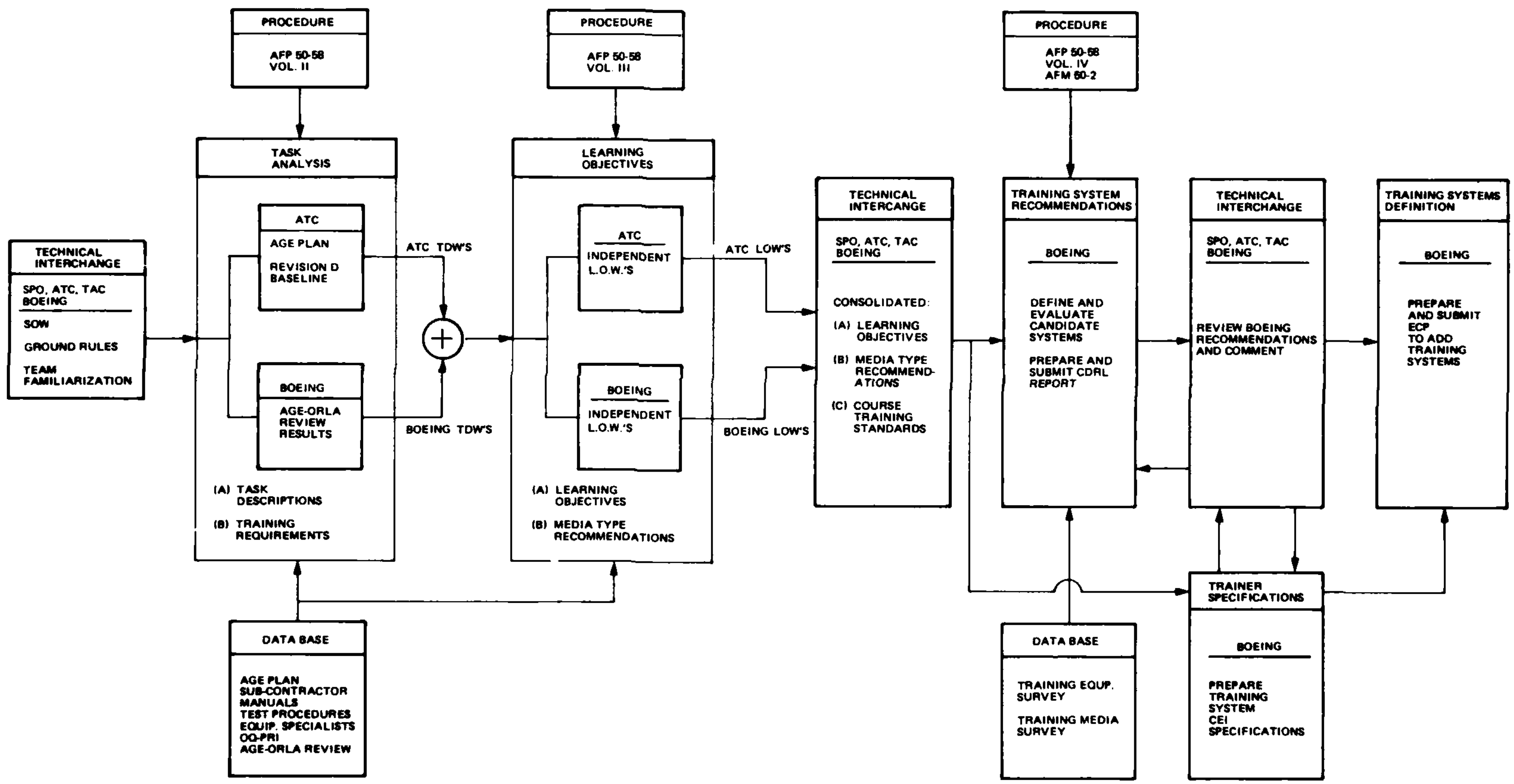



FIGURE 1. FUNCTIONAL FLOW DIAGRAM
AWACS MAINTENANCE TRAINING EQUIPMENT REQUIREMENTS ANALYSIS

CANDIDATE SYSTEMS DESCRIPTION

A — ACTUAL EQUIPMENT TRAINING SYSTEM (AET)
B — COMPUTER AIDED TRAINING SYSTEM (CATS)
C — COMBINED AET/CATS

| ITEM NO. | TRAINING EQUIPMENT EVALUATION CRITERIA TITLE | WEIGHING FACTOR | TIMES | CANDIDATE SYSTEM RATING A | B | C | D | E | EQUALS | ADJUSTED RATING A | B | C | D | E | DIVIDED BY NO. OF APPLICABLE CRITERIA ITEMS EQUALS | NORMALIZED RATING A | B | C | D | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | ONBOARD TASK TRAINING | | | | | | | | | | | | | | | | | | | |
| 1.1 | ACCESS | 1 | | 4 | 4 | 4 | | | | 4 | 4 | 4 | | | | | | | | |
| 1.2 | VISUAL INSPECTIONS | 1 | | 4 | 3 | 3 | | | | 4 | 3 | 3 | | | | | | | | |
| 1.3 | PERFORMANCE CHECK | 2 | X | 5 | 5 | 5 | | | = | 10 | 10 | 10 | | | | | | | | |
| 1.4 | FAULT ISOLATION | 2 | | 4 | 4 | 3 | | | | 8 | 8 | 6 | | | | | | | | |
| 1.5 | ALIGN AND ADJUST | 2 | | 4 | 4 | 4 | | | | 8 | 8 | 8 | | | | | | | | |
| 1.6 | REMOVE AND REPLACE | 1 | | 5 | 4 | 4 | | | | 5 | 4 | 4 | | | | | | | | |
| 1.7 | TEST EQUIPMENT USE | 3 | | 4 | 5 | 3 | | | | 12 | 15 | 9 | | | | | | | | |
| | | | | | | | | | SUM | 51 | 52 | 44 | | | ÷ 7 = | 7.3 | 7.4 | 6.3 | | |
| 2. | SHOP TASK TRAINING | | | | | | | | | | | | | | | | | | | |
| 2.1 | VISUAL INSPECTIONS | 2 | | 5 | 4 | 5 | | | | 10 | 8 | 10 | | | | | | | | |
| 2.2 | PERFORMANCE CHECK | 3 | | 5 | 5 | 5 | | | | 15 | 15 | 15 | | | | | | | | |
| 2.3 | FAULT ISOLATION | 3 | X | 5 | 4 | 5 | | | = | 15 | 12 | 15 | | | | | | | | |
| 2.4 | ALIGN AND ADJUST | NA | | — | — | — | | | | — | — | — | | | | | | | | |
| 2.5 | REMOVE AND REPLACE | 2 | | 5 | 4 | 5 | | | | 10 | 8 | 10 | | | | | | | | |
| 2.6 | TEST EQUIPMENT USE | 3 | | 4 | 5 | 4 | | | | 12 | 15 | 12 | | | | | | | | |
| | | | | | | | | | SUM | 62 | 58 | 62 | | | ÷ 5 = | 12.4 | 11.6 | 12.4 | | |
| 3. | TRAINING SUITABILITY | | | | | | | | | | | | | | | | | | | |
| 3.1 | FEEDBACK | 3 | | 2 | 5 | 3 | | | | 6 | 15 | 9 | | | | | | | | |
| 3.2 | PARTICIPATION | 3 | | 4 | 5 | 4 | | | | 12 | 15 | 12 | | | | | | | | |
| 3.3 | REALISM | 2 | X | 5 | 3 | 4 | | | | 10 | 6 | 8 | | | | | | | | |
| 3.4 | SELF-PACING | 2 | | 3 | 5 | 4 | | | = | 6 | 10 | 8 | | | | | | | | |
| 3.5 | SAFETY | 3 | | 3 | 5 | 4 | | | | 4 | 15 | 12 | | | | | | | | |
| 3.6 | RESPONSE RECORDING | 1 | | 1 | 5 | 3 | | | | 1 | 5 | 3 | | | | | | | | |
| 3.7 | AVAILABILITY | 3 | | 2 | 5 | 3 | | | | 6 | 15 | 9 | | | | | | | | |
| 3.8 | FLEXIBILITY | 2 | | 3 | 4 | 3 | | | | 6 | 8 | 6 | | | | | | | | |
| | | | | | | | | | SUM | 51 | 89 | 67 | | | ÷ 8 = | 7.0 | 11.1 | 8.4 | | |
| 4. | SUPPORT REQUIREMENTS | | | | | | | | | | | | | | | | | | | |
| 4.1 | SUPPORT EQUIPMENT | 2 | | 4 | 4 | 4 | | | | 8 | 8 | 8 | | | | | | | | |
| 4.2 | FACILITY | 2 | | 3 | 5 | 4 | | | = | 6 | 10 | 8 | | | | | | | | |
| 4.3 | MAINTENANCE | 2 | X | 1 | 4 | 2 | | | | 2 | 8 | 4 | | | | | | | | |
| 4.4 | COMPUTER PROGRAMS | 2 | | 4 | 1 | 2 | | | | 8 | 2 | 4 | | | | | | | | |
| 4.5 | NEW HARDWARE | 2 | | 5 | 3 | 4 | | | | 10 | 6 | 8 | | | | | | | | |
| | | | | | | | | | SUM | 34 | 34 | 32 | | | ÷ 5 = | 6.8 | 6.8 | 6.4 | | |

FIGURE 2. AWACS TRAINING SYSTEM EVALUATION WORKSHEET FOR NAVIGATIONAL COMPUTER SYSTEM

to all concerned. Responding to historical ATC and TAC preferences for actual equipment for maintenance training, the contractor offered to supply actual equipment trainers at an estimated cost of approximately $35 million. This sum did not include costs of support equipment required to meet reliability/maintainability specifications. By January 1976, when costs for support equipment were included, the proposed costs for actual equipment trainers had ballooned to approximately $50 million. This sum greatly exceeded the funds programmed for maintenance training equipment for AWACS mission avionics.

## E-3A SPO Cost/Benefit Analysis

Faced with this situation, human factors and training specialists in the SPO prepared, with AIR assistance, a Cost/Benefit Analysis showing the amortized cost per trainee for the relatively small numbers of trained personnel (11 to 70 per year) required to man TAC maintenance positions for the fleet of 15 aircraft then under contract. Prorated over a 15-year life cycle, maintenance training equipment costs would have ranged from $21,000 to $80,000 per trainee. This study postulated and explored the consequences of a decision to drastically limit MTE procurement to static devices and visual aids for classroom training (relying on the T.O.s and student handouts), deferring actual "hands-on" practice to on-the-job training at TAC bases. This "devil's advocate" approach produced prompt and constructive responses from TAC and ATC, generally favoring a pragmatic mix of a) selected end-item equipment with which ATC would construct its own communication trainer; b) second-shift operations at TAC bases to train computer maintenance technicians using already-available AWACS operator training equipment; and c) low-cost front-panel simulators for the radar and navigation training equipment.

In March 1976 the E-3A SPO approved this pragmatic approach to a cost effective solution of training requirements. This approval was qualified by a recognition that availability of adequately defined procedures in technical orders should be a prerequisite to purchase of testing equipment. In May 1976, ATC proposed design guidelines and preliminary functional requirements for a front-panel simulator to support training for the navigation systems. An ATC preference for the extensive use of off-the-shelf equipment in the simulators and a competitive procurement for them was endorsed by the E-3A SPO at a TI meeting in June 1976, at which time AIR commenced work on the Prime Item Development Specification (PIDS). Competitive bidding resulted in award of a contract to Honeywell on 30 May 1978 and the ASN-118 (T1) simulator for the E-3A Navigation Computer System was delivered to Keesler Technical Training Center 18 months later in December 1979.

# PART II: THE MAINTENANCE PROCEDURE SIMULATOR (MPS)

Trainer design and development is a disciplined symphony made up of concepts, components and people. The maintenance trainer is a recent addition to the host of, among others, operator and operational trainers for sonar and avionic systems. Upon first look at the maintenance trainer, one can get lulled into a feeling that these type of trainers are relatively simple requiring less development rigor and discipline than previous device types. This would be a serious mistake in both time and money.

Maintenance trainers primarily use off-the-shelf components, well-proven equipments, all within today's technology. Difficulties in development schedules and cost arise because from past experience we typically estimate that the complexity of the device is equivalent to the complexity of the hardware. Hence, based on previous experience, we tend to underestimate the total scope of effort. Although the hardware is straightforward, the maintenance trainer is complex in the software and instructional features domain. The development approach for the maintenance trainer device must be carefully conceived, well-defined through specification and controlled through management disciplines.

## The E-3A MPS Design Concept

The purpose of the E-3A MPS is to supplement classroom training of organizational level maintenance personnel on the AN/ASN-118 Navigation Computer System (NCS). The MPS is designed to demonstrate operation and checkout of the NCS. This includes the simulation of malfunctions and maintenance procedures. The MPS functions as a procedural trainer in that the following maintenance can be performed:

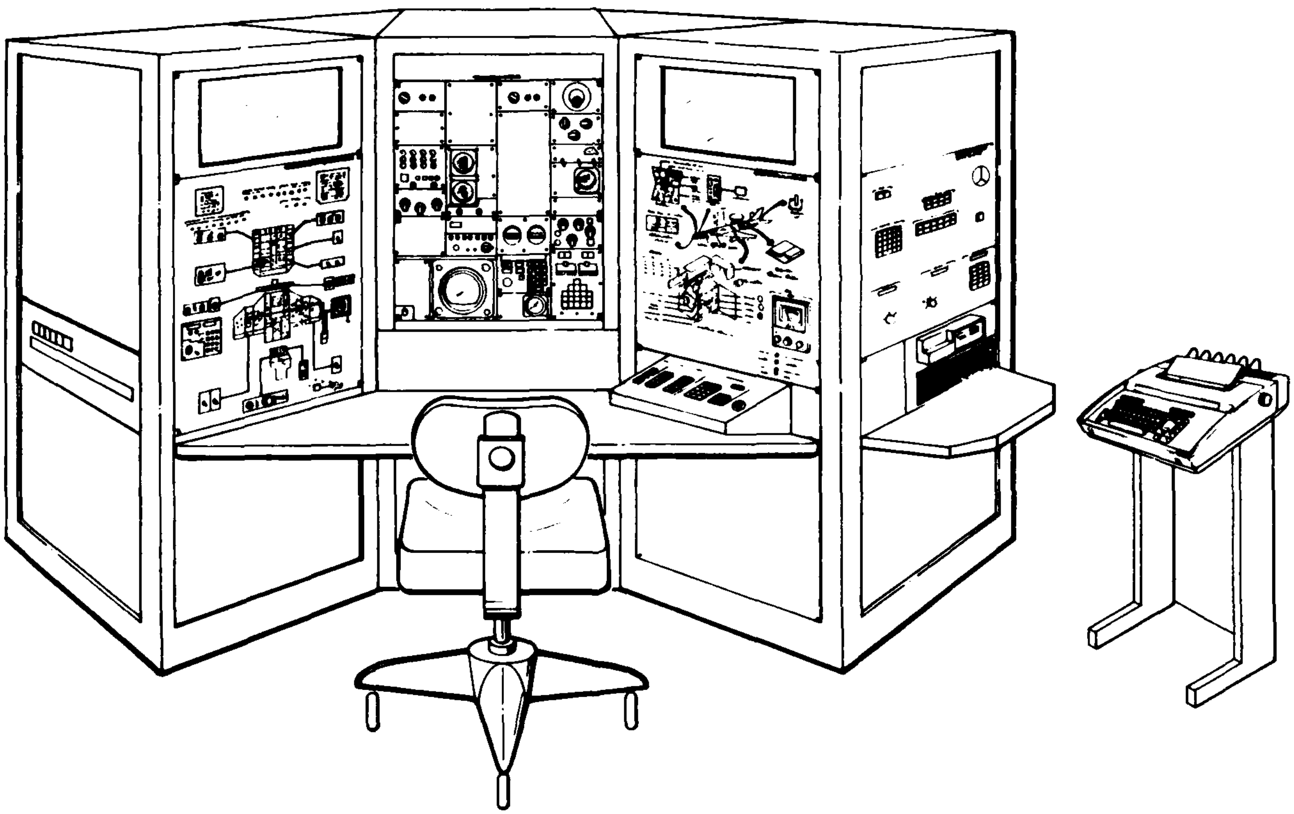
1. Fast System Checkout
2. Complete System Checkout
3. Trouble Analysis
4. Subsystem Performance Checks
5. Post Replacement Checkout Procedures

The MPS is augmented with real-time models in order to support part task training on the Inertial Navigation System (INS) as well as the NCS. A mix of simulated and real components for various E-3A avionic equipments are mounted on flat panels to provide hands-on manipulation of equipment during lessons. A pictorial of the device is presented in Figure 3

## The Detail Design Specifications

A formal method to clarify a PIDS and document the system definition is necessary for development contracts. A first step towards achieving this objective is to make a comparison of the PIDS and the submitted proposal. The PIDS provides the information on what is required, the proposal provides information on what is priced. Any contradictions in the intent of these documents should be clearly identified as early as possible in the

Figure 3. E-3A Maintenance Procedure Simulator



project and result in specification changes. During the definition phase, all other clarifications should also be prepared and submitted as changes to the PIDS. Formal changes provide a clear trail as to what agreements have been reached between customer and contractor. The updated PIDS serves as a functional baseline for detailed product and software specifications.

A maintenance trainer, such as the E-3A MPS, is not meant to exactly duplicate all of the workings of the original equipment. The specifc functions and malfunctions of the operational equipment must be specified prior to software development and fabrication.

With a clearly defined PIDS, plus detailed maintenance procedures, a Computer Program Development Specification (Part I software requirement specification) can be drafted. The CPDS maps the software requirements from the PIDS into stand alone documents. Care must be taken in generation of the CPDS to present requirements, not implementation. It is important not to design the software system in the CPDS as this often precludes functional group participation and can lead to a less than robust software design.

To achieve system definition for the E-3A MPS, a System Specification was generated. This was an internal working document, which defined the system concepts and allocated functions to hardware, software and courseware. It was accessible to the project team and communicated the system as it evolved through the definition phase. This document was allowed to become obsolete upon conclusion of the design phase with the issuance of product and software specifications.

## The Software System

In general, software systems for maintenance trainers interface with a wide variety of peripherals as well as panel(s) with multiple switches, rotaries, analogs, keyboards and other miscellaneous components which represent various aircraft subsystems. The software system provides the functional capability to allow for interface with the instructor for lesson preparation and control, as well as student monitoring. The functional capability to allow student interface with the trainer must also be provided.

The CPDS provides to what extent the student and instructor has to interface with the device. Also provided is the degree to which various components are required to be simulated.

The software architecture for the E-3A MPS is presented in Figure 4. It represents the approach Honeywell developed to meet the E-3A MPS requirements. The system is based on transposing Technical Orders (T.O.s) into an intermediate language, and compiling that language to form a data base. During a lesson the data base is used to provide the instructional portions of the simulation.

Specifically, the T.O.s are transposed using the Courseware Author's Language (CAL). The CAL was developed specifically for this purpose and Provides a productive means of presenting T.O. information in a high order language. The CAL is compressed through use of the Courseware Author's Language Generator (CALGEN). CALGEN takes the higher order language and transforms it into a compressed data base called Primitive Courseware Language (PCL). CALGEN provides error diagnostics and various user aids.

The application software is composed of two primary parts: specific trainer software and the Procedure Monitor. The specific trainer software is composed of the input/output processors, real-time model functions, and the instructor/trainee processors. The Procedure Monitor is the real-time interpreter which translates the PCL into actions based upon panel inputs.

Honeywell feels that this architecture is flexible and allows for change. This is important in maintenance trainers in that panel components can change as well as fidelity requirements over the life of the system.

For the E-3A MPS, two specific devices, the INS and NCS, were to be high fidelity, real-time simulations. Defining how the INS and NCS worked to the extent necessary was done very well. The INS and NCS work well enough to "fool" the student as well as the instructors into believing that they are actual devices. To give an example of the degree of fidelity, the INS activated switches on depression while the NCS activated switches on release, this was simulated in the trainer. In interfacing these models with courseware, two concepts should be kept in mind.

1. Courseware/software interfaces should be as simple as possible.

2. Courseware interfaces should be as transparent to the software as possible.

These aforementioned items will aid in making the software and courseware development simpler.

## The Courseware

The courseware starts out as a T.O., and winds up as a compressed data base stored on disk. The manner in which the courseware evolves from T.O. to language is called T.O. Annotation. The annotation of T.O.s is a result of training analysis and human factors engineering. As a result of the annotation, the T.O. becomes a detailed explanation of how the lesson should operate.

For the E-3A MPS, the PIDS specified that there should be varying visual aids to the student, based on an instructor selected input. Hence, rules were laid out in order to properly annotate the T.O.s for slides. Additional rules corresponded to maintenance action slides, set-up slides and error slides. Besides annotation, the T.O.s had to be transposed into the CAL. This was accomplished through a set of rules which were taught to the courseware authors These rules were then expanded using computer automation.

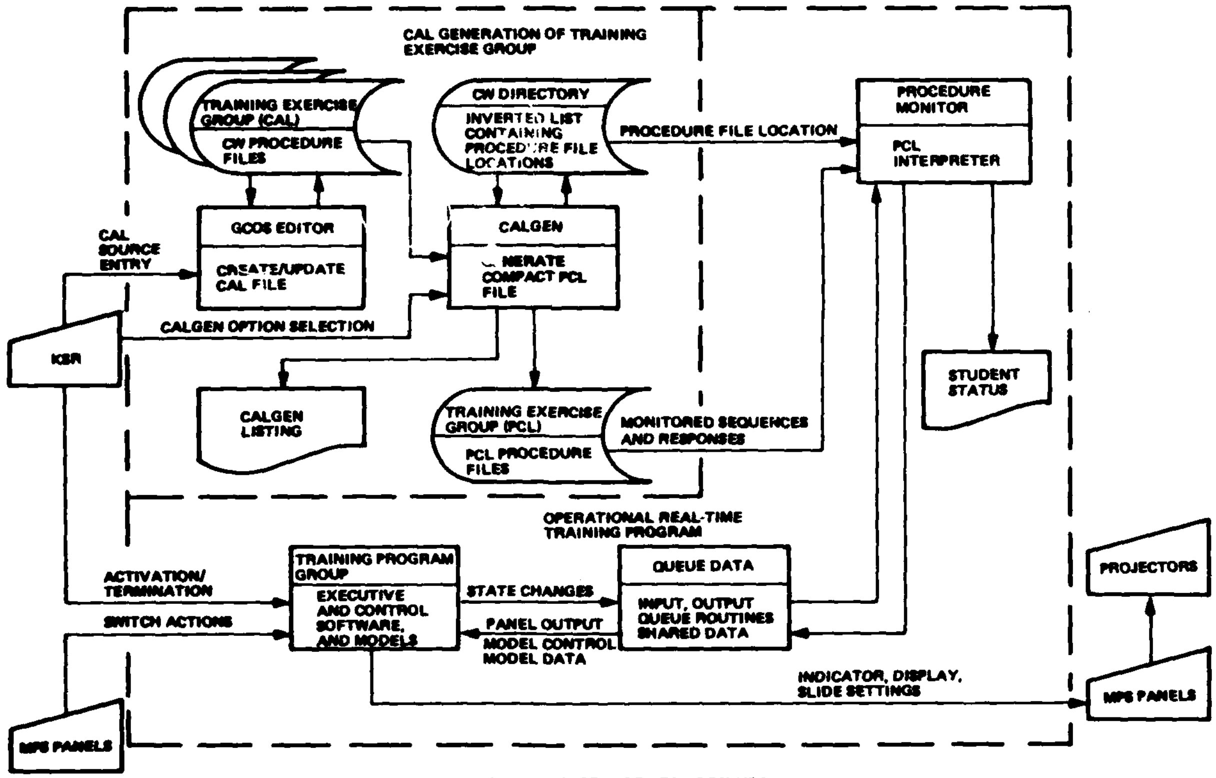



FIGURE 4. E-3A MP. SOFTWARE ARCHITECTURE

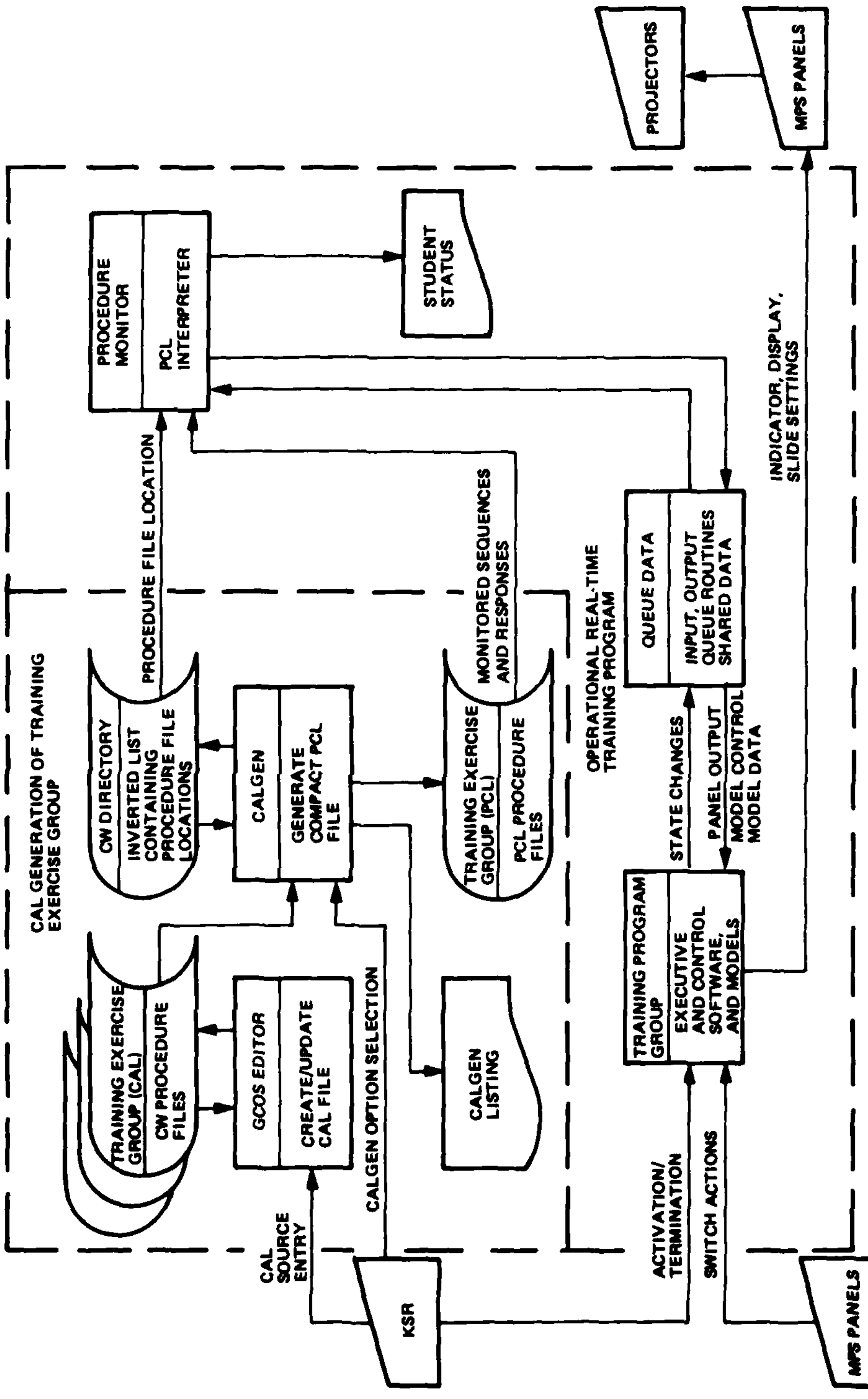



FIGURE 4. E-3A MPS SOFTWARE ARCHITECTURE

The results of this approach to generating the CAL was very satisfactory. The 273 lesson units developed for the E-3A MPS meet their lesson objectives.

The Hardware System

As discussed previously hardware systems for maintenance trainers are relatively simple, making use of off-the-shelf equipment as much as possible. The E-3A MPS is no exception. The E-3A MPS is composed of a Honeywell Level 6 Model 43 minicomputer with 128K of memory, a 10 Mbyte disk, ASR-43 teletype, 2 Mast projectors and various panel components.

A key concept used during the E-3A MPS development was an automated data base defining the possible states of the panel components. The data base listed all inputs and outputs on each panel, type of component, word and bit of each item as read/written to the panels. The data base was used to provide information to the functional groups interfacing with the trainer: software and the digital groups. If a change occured in the hardware, the data base was changed and copies provided to the users. This list was automated and was invaluable in interfacing with the trainer.

*Integration*

There are two phases of integration for the maintenance trainer. The first integration phase is the conventional software with hardware marriage. The second phase of integration is when the courseware is fully integrated with the software and hardware.

The software integration for the E-3A MPS was more complex in that the courseware interpreter, Procedure Monitor, also had to be integrated. The software integration plan was multi-staged such that both the application software, and the Procedure Monitor was integrated with each other and then with the hardware.

During the software integration, care must be taken to define appropriate tests so that any of the software/courseware interfaces can be exercised. Eventually, all such interfaces are required to be tested.

Courseware integration must be done upon completion of software integration. It involves system functional testing as well as verifying that all lesson units are operational. All functional level testing should be against requirements. Lesson units should be verified through operation of T.O.s, lesson plans or material of that nature. Annotated T.O.s are extremely useful to verify the courseware. During the E-3A MPS courseware integration, we mistakingly used listings to verify the courseware. However, verifying the listing does not mean that the courseware is correct. We eventually used the T.O. and the instructors guide to verify the lesson units.

During system integration of the E-3A MPS it became painfully clear that courseware tools were required for debugging. We produced a courseware debugger, which matured during the E-3A MPS integration phase.

In the future, it is suggested that courseware tools be set up such that courseware testing can be automated to as large a degree as possible. Variability in student response leads to an infinity of parameters to be tested. With at least a minimal amount of automation, high confidence in testing can be achieved.

This is exactly how testing evolved on the E-3A MPS. We eventually used a courseware tool, "virtual student", to verify that each branch of courseware was valid and would operate successfully. We would then verify the lesson unit. If any branch required additional testing we used another tool to start at the correct courseware step. In this manner, with these tools, we were able to complete verification of all lessons and hence, finish system integration.

Conclusions

The conclusions to be drawn about maintainance trainer development from the E-3A MPS experience are presented as follows:

1. Provide robust software architecture able to accomodate changes as well as additional real-time models.

2. Control T.O. annotation or lesson unit generation carefully. Automate the process, to at least allow for interfacing purposes and consistency in documentation.

3. Control PIDs/Proposal to system definition and then through requirements documents. If the specifications are controlled and communicated, the project will procede more smoothly.

4. Test to the PIDS and the T.O.s. Do not test to anything artificial unless agreed upon with the customer.

5. To the largest extent possible, automate testing. Find a point which provides cost effective testing with a reasonable confidence level.

The E-3A MPS has been delivered to Keesler AFB. Three classes have been given, as of July 31, with successful results. The device has been operating without significant maintenance problems for greater than 5000 hours. All software and courseware deficiencies have been corrected under the warrenty provision of the contract. We have remained in close contact with the users and feel that the E-3A MPS represents a successful culmination of our joint efforts.

## ABOUT THE AUTHORS

Mr. David L. Winter is a Senior Research Scientist at the American Institutes for Research in the Behavioral Sciences. Mr. Winter has served as project director responsible for design of computer base maintenance procedure simulators to train technicians for the E-3A AWACS Avionics System and participated in preparation of design specifications for the USAF Base and Installation Security System. Mr. Winter holds a B.A. degree from the University of Pittsburgh, a certificate in Russian from Syracuse University, a M.A. degree from Columbia University and a certificate in computer science from the Northeastern University.

Mr. Michael F. Sturm is the E-3A AWACS Engineering Manager for Honeywell, Inc, Training and Control Systems Center. Mr. Sturm has participated in the design and development of various trainers for Honeywell including the FBM Sonar Operational Trainer, the device 21B64, 14E24 PAIR and 14E35 IVDS. Mr. Sturm holds a B.S. degree in mathematics from the Polytechnic Institute of Brooklyn, and a M.S. degree in mathematics from the California State University at Los Angeles.

# PERFORMANCE TECHNOLOGY IN THE ARMED FORCES:
# NEW TECHNIQUES FOR MAINTENANCE
# TRAINING SIMULATOR DESIGN

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for
Presentation at Second Interservice/Industry
Training Equipment Conference
Nov 18 - 20, 80 Salt Lake City, UT

This presentation describes a portion of the Human Resources Laboratories continuing investigation of simulators for use in maintenance training. Further details may be found in Hritz, R. J., Purifoy, G. R., Jr., and Smith, J. A. Maintenance Training Simulator Design and Acquisition: final report. AFHRL-TR-80-23. Lowry AFB, CO: Technical Training Division, Air Force Human Resources Laboratory, April 1980.

## OBJECTIVES

The increasing complexity of modern Air Force weapon systems and a decreasing Air Force training budget have combined to produce a maintenance training problem that demands cost-effective improvement in maintenance trainer design and acquisition. The project was designed to address four objectives:

1. To document the existing Instructional System Development (ISD) Process, particularly those procedures directed toward designing maintenance training equipment and documenting training equipment requirements.

2. To document the existing System Program Office (SPO) procedures for acquiring maintenance trainers.

3. To develop new training technology and tools to assist the ISD analysts to identify training equipment requirements (e.g., the level of fidelity) and to develop a procedure or mechanism to communicate these to SPO personnel.

4. To develop procedures to assist the Acquisition Manager and his support personnel prepare a procurement specification suitable for distribution to vendors and contractors.

Two of the objectives were directed toward the ISD side of the acquisition process, while the remaining two objectives were directed toward the SPO side of the acquisition process.

## APPROACH

The two sides of the acquisition process were approached in a similar fashion. ISD and SPO personnel were interviewed to determine the existing procedures. Because procedures varied between Air Force organizations performing these functions, model processes were constructed.

The ISD and SPO procedures were then carefully analyzed to determine problem areas; areas where improvements could be realized.

Procedures were developed to assist the ISD analyst in making critical training equipment design decisions (e.g., determining if a maintenance simulator is required, determining the degree of fidelity of the components to be represented on the trainer, and selecting and defining the instructional features that are processor-controlled and facilitate managing the training situation). All such procedures are presented in a flow chart decision-making format.

To assist the ISD analyst in communicating the results of the ISD analysis, a model or generic ISD-derived training equipment design specification was developed. This model specification describes such training requirements as the training objectives, a training application plan or model, a physical and functional description of the components to be represented, a comprehensive description of the processor-controlled instructional features and a configuration plan for the intended trainer.

To assist the preparer of the procurement specification, a model or generic Prime Development Specification was developed. This generic specification contains both engineering and training requirements. The training requirements are derived from the ISD-derived training equipment design specification. The engineering requirements are established from Military Standards and Specifications. Accompanying the generic specification is an Appendix-Handbook which provides guidance and instruction to a specific application.

Both the ISD-derived and SPO model specification have the same format. Since both specifications are generic, they contain paragraphs and sub-paragraphs which are appropriate in a variety of situations (e.g., to describe requirements for both O- and I-Level maintenance trainers). So that the specifications can be tailored to any situation, the paragraphs contain blanks to be completed by the preparer. The blanks provide an opportunity for the preparer to insert the necessary requirements for their particular situation. It should be noted that the format of the specifications permit requirements established in the ISD-derived model specification to be traced thru the procurement documentation to the final acceptance test of the trainer. This should assure that the trainer obtained does, in fact, provide the required training.

Since the specifications are generic, a set of instructions accompany them.

The instructions provide guidance on selecting the appropriate paragraphs and sub-paragraphs for specific applications. Also provided in the instructions are directions for establishing the needed requirements (i.e., completing the blanks) and included are references to the appropriate Military Standards. Included in the instructions is a section on Lessons Learned--this section discusses what has been learned about establishing and stating requirements from previous trainer acquisitions.

RESULTS

The ISD-project-developed materials were reviewed by the 3306th Test and Evaluation Squadron (Edwards Air Force Base, California). The SPO Project-developed materials were reviewed by personnel from ASD/EN (Wright-Patterson Air Force Base, Ohio). Comments about the material were generally favorable. The concept of having two specifications was viewed as workable and desirable and as a way to assure that the ISD-derived training requirements would not be misunderstood or distorted in the final procurement specification. Furthermore, the format of the specifications was very well received; i.e., it provided flexibility yet standardization.

In addition to describing the project activities and products produced by the project, the Final Report also discusses several problem areas (e.g., the impact on the ISD analysis from an accelerated maintenance training acquisition cycle). Nine problems are discussed. Accompanying the description of the problem is a list of recommendations. Areas for future research are also identified and discussed.

ABOUT THE AUTHOR

Dr. Edgar A. Smith, Research Psychologist, United STates Air Force, Lowry AFB, Colorado. Engaged in design and evaluation of maintenance training simulators and in the development of handbooks for design and procurement of such devices.

# THE SIMULATOR DATA TEST INSTRUMENTATION SYSTEM

## A NEW CONCEPT IN TRAINING DEVICE FIDELITY MEASUREMENT

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ABSTRACT

The Air Force recently completed in-house development of an instrumentation system designed to measure flight simulator cue correlation, aero model fidelity, and dynamic flight handling characteristics. The Simulator Data Test Instrumentation System (SDTIS) represents a significant advance in the state of the art for flight simulation instrumentation. The SDTIS hardware is configured as a field transportable "mini-system" using composite video recording techniques to concurrently record over 180 channels of analog or digital signal data, voice audio, and television camera acquired video information. It provides immediate, in-field, automated data reduction and analysis. It permits data acquired during simulator test to be directly compared to flight test data as a measure of simulation fidelity. The Air Force intends to use SDTIS techniques as an integral part of future simulator test and specification procedures. This paper will address the SDTIS capabilities, functions, and operation in conjunction with its application to future training equipment procurements.

### BACKGROUND

Military and commercial use of flight simulators for crew training has expanded rapidly in recent years in response to the rising cost of energy and new aircraft. Simulator based training systems now enable commercial airlines to transition crews from one aircraft to another (i.e., DC-9 to DC-10) with as little as one hour of actual aircraft flight time. Current trends indicate that non-revenue (training) flights may be completely eliminated by some airlines in the near future as the effectiveness of both simulator hardware and related instructional systems is improved. Military flight simulation has traditionally been more demanding of technology than its commercial counterpart. When compared to airline flight operations, military flight tasks are more difficult, involve more diverse and complex systems, and demand development of vastly more complex simulators. Future military flight crew training programs will depend on use of a "family" of training equipment, ranging from table-top part task trainers to fully integrated weapons systems trainers (WST). The most complex of these simulate not only the airframe flight dynamics, basic flight instruments and controls, but also closely duplicate the control stick "feel", cockpit motion, vibration, buffet, and the pilot's complete external visual field of view. Visual displays provide a complete 360° out-the-window view of the sky, horizon, ground terrain, airbases, ground targets, ground threats, airborne surface to air missiles, and other aircraft. Radar and electronic viewing system sensor imagery (forward looking infrared television - FLIR) is also provided, in conjunction with simulations of imagery generated by precision guided munitions and other weapons release and guidance systems. Navigation systems and electronic warfare equipment functions are also simulated. Thus, the WST represents a fully integrated trainer.

As pressure to trade-off flying hours for simulator time has intensified, military simulator users in turn have demanded simulation fidelity far beyond that which would have been acceptable in years past. This leads to consideration of simulator "cue" fidelity and "cue" correlation, which are discussed in the paragraphs which follow. Flight simulators may be viewed as closed "man in the loop" systems, wherein the simulator hardware is expected to provide accurate cues in response to pilots' control inputs. This concept has conventionally been applied to aeronautical performance parameters; however, it may likewise be applied to simulation of systems for navigation, electronic warfare, fire control, precision guided munitions control, and more. The concept in each case is the same; the simulator pilot makes inputs through his controls, and expects to perceive appropriate "cues" in response.

Proper "correlation" of the simulator cues is essential for any simulation. Human physiology allows us to sense an event time difference as small as 100 milliseconds. For example, if a man operates a switch controlling a lamp, and the lamp does not illuminate within 100 ms after the man moves the switch, he will be aware of the time delay. Thus, it is important that the simulator produce accurate cues which are properly time correlated with the control movements <u>and</u> with the other cues produced. Visual or motion simulation systems which respond to control inputs 400 or 500 milliseconds after the panel instruments react will be of little value. Moreover, it is important that the cues not only <u>start</u> at the proper time, but also that their <u>magnitude</u> versus time be matched to the aircraft performance. Matching of simulator cue time histories with those perceived by pilots in the aircraft thus becomes a major simulator design task. Failure to do so inevitably results in unhappy simulator pilots who report that the simulator "doesn't fly like the airplane." Quite often they can't tell you <u>why</u> it doesn't fly right; they merely perceive a difference. In most cases, that difference can be quantitatively traced to poor cue fidelity, or poor cue correlation. Of course, simulation is a cheating game; it is not technically possible to perfectly duplicate many cues. Designers must therefore be both clever and innovative in "tailoring" the cues available within the state-of-the-art such that perception of cue errors is minimized.

Development of flight simulator cue fidelity is largely a "black art." Each contractor pursues the matter a little differently. Initial success is highly dependent on the quality of aerodynamic performance data available from aircraft flight test sources. More often than not, data available falls far short of that needed for development of a high fidelity simulation. Reasons are numerous. Quality data may be unavailable due to the fact that a simulator is being developed concurrently with the aircraft, forcing use of generic aero models, wind tunnel data, iron bird characteristics, etc. Quite often, the only aero data available is based on tests of previous aircraft configurations which differ considerably from that to be simulated. As a rule, the only aircraft test data recorded and preserved is that required for airframe acceptance or performance evaluation; data characterizing the full spectrum of systems and cues perceived by the pilot is not acquired or preserved. At best, data available allows simulator designers to develop a good aerodynamic model. However, one must recognize that the aero model represents only one link in the chain of signal processing which occurs between the pilot's control input and cues produced. Flight test data is normally not acquired which can be used to support the "end to end" test concept discussed above.

Past simulator acceptance tests have been based on performance of a "family" of tests. Wherever possible, peripheral systems (such as electronic warfare hardware) are tested independently. Limited tests of the computer's aero module (which look only at the aero model, and do not consider data processing of control inputs, cue drive outputs, linkage delays, etc. which occur before and after the aero model) are performed using spare computer digital to analog outputs and strip chart recorders. Handling qualities (including control stick response) are measured statically. No multiple axis, dynamic tests are performed quantitatively. These tests are left to test pilots who evaluate the simulator performance subjectively. Thus a pilot is the first evaluator of integrated simulator performance. Government test procedures have normally required a subjective simulator evaluation by teams of experienced pilots wherein the contractor was required to make hardware and software adjustments until the dynamic simulator performance matches the pilots' memory of aircraft performance. Unfortunately, pilots became "simulator acclimated" in just a few days. All too often, simulator performance acclaimed as adequate by one team was judged inadequate by the team that followed. This subjective procedure usually resulted in an endless iteration of tests. There was no method of tracking a performance fidelity baseline. Such handling qualities tests ultimately delayed simulator deliveries at great expense to both contractor and government.

## FUNCTIONAL CONCEPT

Functional concepts for the Simulator Data Test Instrumentation System were developed by Air Force engineers based on their experiences in the subjective domain discussed above. The SDTIS embodied two basic concepts. They were:

1. That it should be possible to quantify simulator handling qualities and track handling qualities changes through use of "end to end" system measurements; i.e., a comparison of cue time histories versus control input time histories, and

2. That, if given identical control inputs, the simulator and aircraft would produce "comparable" cue time histories. The first concept is now well proven; the second is still on trial.

Functional SDTIS requirements included the ability to:

a. Quantitatively measure and record the magnitude, phase, and time relationship of simulator cues produced in response to standard dynamic, multi-axis control inputs. The recording capability must include simultaneous, synchronous acquisition of analog and digital signal data, optically acquired data such as dial pointer positions and visual display positions, g-seat and g-suit forces, motion platform position and acceleration, stick position, and stick force.

b. Make measurements of cue time histories produced in response to multi-axis control inputs produced by a mechanized, automated, simulator stick (and rudder) mover. The control movers must be programmable to produce standard reference inputs (step, ramp, and sine) as well as to duplicate aircraft control movements made by test pilots flying missions from which simulator reference data was taken.

c. Automatically reduce data recorded into forms readily useable by simulator engineers. In field co-plots of time histories were required as a minimum. (Cross plots were subsequently added as a requirement.)

d. Automatically compare (through on-site, in-field plots) data recorded against that obtained from flight test and other data sources.

e. Self calibrate, automatically scale, and label all data recorded.

f. Be field portable such that the system could be easily transported (as airline luggage if necessary) to contractor facilities or Air Force field sites.

## DEVELOPMENT STATUS

Development of the SDTIS was initiated in January 1978 as an in-house activity performed by the Visual and Electro-Optical Branch of the Simulator (Engineering) Division of the Aeronautical Systems Division (ASD). Program funds and support contract management were provided by the ASD Simulator System Program Office. This effort is now nearly complete. Ninety per cent of the design, and 50 per cent of the fabrication was performed as an "additional duty" responsibility by Air Force simulator engineers, technicians, and cooperative engineering students who were also required to support simulator acquisition programs. The balance was performed as sub tasks by a local

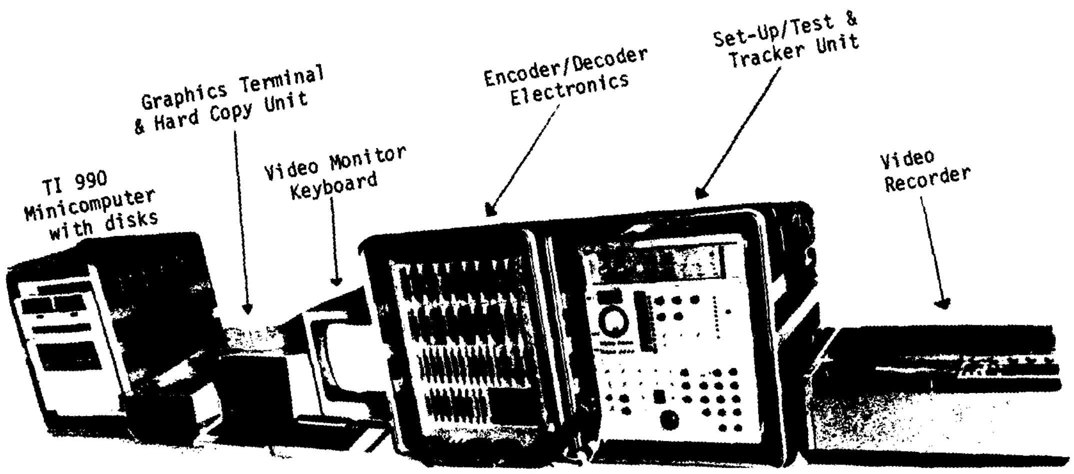


Figure 1

Simulator Data Test Instrumentation System

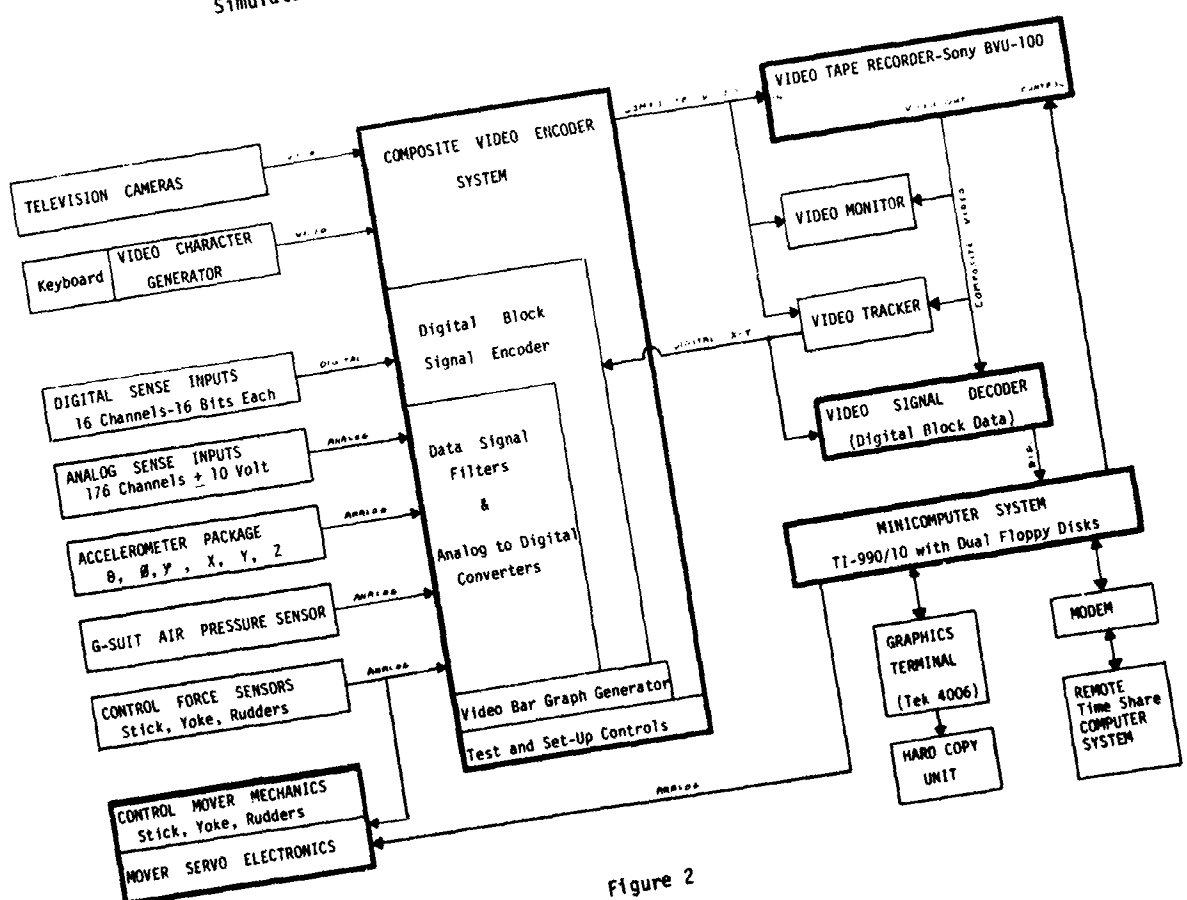


Figure 2

SDTIS Block Diagram

support contractor. All initial design objectives have been achieved; most have been expanded. Development cost to date is approximately $300K for parts and contractor support.

## SYSTEM DESCRIPTION

The SDTIS system (less control movers) is shown in Figure 1, as represented by the block diagram of Figure 2. It consists of a family of sensors, video encoding and decoding electronics, a video recorder, a mini-computer, graphics terminal with hard copy unit, and a family of control movers. The functions of each subsystem will be discussed below.

### Sensors

Six basic sensors have been provided for simulator instrumentation. These are:

Analog Signal Inputs - The SDTIS system has the capacity to record 176 channels of analog signal data. The signal encoding, cabling, and filtering subsystems are physically and functionally organized into blocks of sixteen channels. Analog signals (from simulator electronics, backplanes, etc.) are acquired through the use of alligator clips, J-clips, push on connectors, etc., and are connected to terminal blocks on J-boxes (or spider boxes). See Figure 3. Each J-box accommodates sixteen signals. Fifty foot lengths of multi-wire cable are then used to connect the J-boxes to the encoder electronics rack. Analog channel inputs are differential with input impedances which exceed one meg ohm (limited only by the cable capacitance). Portable, hand held, battery operated isolation electronics are used where signal loading is a problem and additional isolation is required. Simulator signals thus acquired include control force and position follow-up signals, command and follow-up signals for visual system servos, motion platform servos, panel instruments, and g-seat bellows.

Digital Signal Inputs - The SDTIS system, as currently configured has the capacity to record sixteen 16-bit digital channels. Signal input mechanics are configured much like the analog inputs discussed above, except that the J-boxes house active electronics which:

a. provide additional isolation

b. provide for digital word latching triggered by an external signal (master clock or signal valid), and

c. accommodate digital inputs of varying thresholds, polarities, etc.

Each J-box handles one 16-bit input.

Motion Sensors - A motion sense package has been provided for motion platform acceleration measurements. The package consists of a three axis rate gyro, three linear accelerometers, and the associated electronics. (Rate gyros were chosen in lieu of angular accelerometers based on cost, availability and maintainability.) This package would normally be located at the pilot's seat; however, math exists and field operable software is under development that will permit comparison of measurements taken from anywhere on the motion platform with flight test measurements taken from anywhere on the airframe.

G-suit Air Pressure Sensor - A g-suit air pressure sensor has been provided to enable cue correlation between the g-suit, g-seat signal drives, and the motion platform.

External Position Follow-Up Sensors - Retractable string connected position sensors have been provided for measurement of control and servo movements in areas where internal simulator follow-up signals are unavailable or cannot be trusted.

Control Force Sensors - Force sensors have been acquired for stick, wheel/column and rudder control inputs.

TV Cameras - Three television cameras (one low light level intensified silicon vidicon, one Newvicon, and one silicon vidicon) have been provided for acquiring cues which are not available as electronic signals. Instrument panel dial pointer movements and visual display movements are of primary interest. Many simulator flight instruments are dc-servo replications of actual aircraft instruments - hence instrument response delays required to match aircraft instrument performance (cue correlation) are a simulator software function. Simple measurement of instrument command signals may be inadequate for cue correlation work using the "end to end" test concept. A video tracker, capable of either edge or centroid tracking, has been provided to enable dial pointer/visual horizon position tracking. The tracker functions in conjunction with electronics which "mask" instrument or display geometry which may confuse the tracker. For example, a donut shaped mask is used to track dial pointers, so that the tracker is permitted to see only video from the arc transcribed by the dial pointer tip.

### Data Encoder/Decoder

The encoder/decoder shown in Figure 4 is responsible for formatting all of the sensor signals discussed above into a composite video signal suitable for recording by a standard video recorder. The composite television picture format recorded is illustrated in Figure 5. The first 15 per cent of each TV line is committed to hosting a 16-bit digital word. Thus, a "digital block" appears along the left edge of the TV picture which accommodates 240 words per TV field. All signal data is recorded in a digital format within this "digital block." The remaining TV picture area (amounting

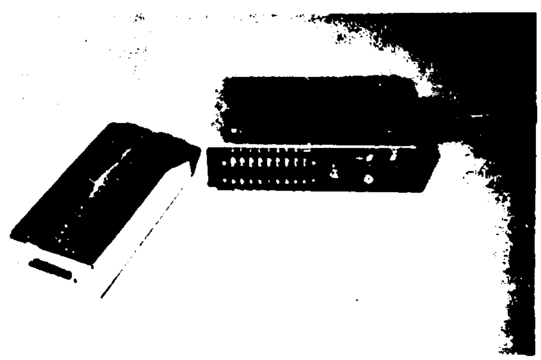

Figure 3

Analog and Digital Sense Boxes

to 85 per cent of the active TV picture) is available for recording of TV camera video and for display of labeling information. Within the digital block, 176 words are assigned to analog signal data, 16 words to digital signal data and 48 words to data labeling information. Hardware signal filtering is available for selected analog input channels with various cut-off frequencies available from 30HZ to 240HZ.

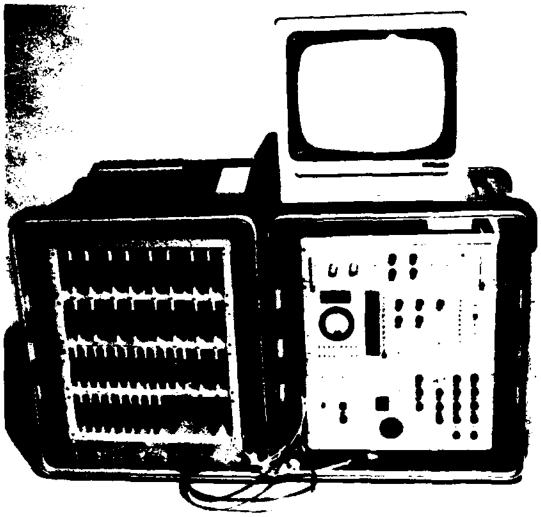

Figure 4

Encoder/Decoder Electronics
with Built-In Test/Set-Up Panel
and Video Tracker Controls

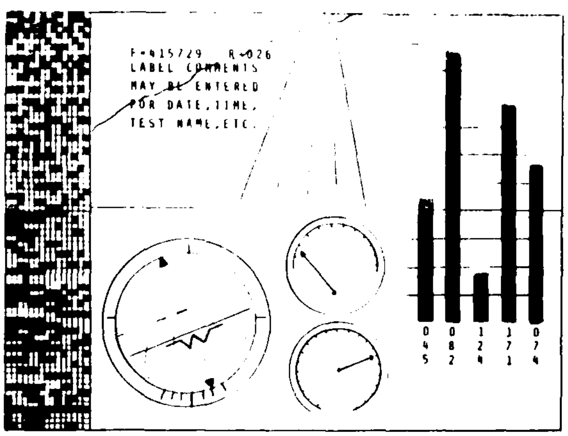


Figure 5

SDTIS Video Format

A video bar graph system has been provided as a test and set-up tool. Up to ten vertical bar graphs may be added to the composite video picture. Any of the 176 analog channel signals may be assigned to any of the 10 bar graphs, with the bar height representing signal magnitude. Bar channel assignments are displayed at the base of each bar. The encoder electronics includes a video character generator for display of "labeling" information. Labeling is performed at two levels. First, each data run is identified with a label which appears continuously in the video picture, indicating run number, the ever changing TV field number, date, time, and miscellaneous comments. Second, each signal channel is labeled with a 64 character identification used to describe the variable name, source, scaling, etc. Channel labels do not continuously appear in the video picture as characters, although they are "scrolled" through the picture at the beginning of each data run. All label information is encoded in the digital block, thus making it available to the in-field computer for proper labeling of graphs and hard copy output data. All labels, bar graph assignments and video image location assignments are controlled (entered) via a TV typewriter keyboard shown in Figure 6. Two channels of audio are concurrently recorded with the data discussed above. These are normally used to record simulator pilot intercom audio and test director comments.

Figure 6

Television Monitor and
TV Character Generator Keyboard

Video Recorder

The SDTIS design concept is based on the use of a commercial, U-matic, 3/4 inch cassette, editing type, video tape recorder as the primary data recording device. (Figure 7 - Sony BVU-200A) A video recorder was chosen because it:

1. was, in fact, a very wide bandwidth data recorder with information recording capacities which vastly exceeded those required for this effort, and
2. was available at very low cost, compared

to available instrumentation recorders of comparable capacity, and

3. allowed integrated recording of audio and video data in addition to the digitally encoded multi-channel signal data, and

4. was easily interfaced to a digital computer allowing automation of data recording and reduction tasks. The SDTIS design concept utilizes only 15 per cent of the active video field for recording the digital encoded signal data. This amounts to a 200 Killobit/second recording capability of one hour duration. If additional digital recording capability were required, the digital block could be expanded over the total active picture area to achieve a 1 megabit/second recording capability.

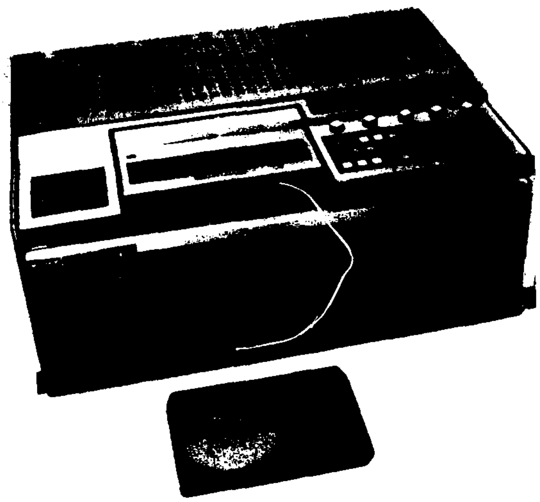

Figure 7

Sony BVU-200A U-Matic Video Recorder

## Recording Characteristics

The above paragraphs describe a very flexible data recording system. The inherent character of the TV signal format used provides a built-in 60HZ signal sample rate for all data recorded. In effect, each data channel is digitized, and recorded sequentially within the digital block. This means that each channel is sampled, sequentially in time 63 microseconds apart. The time shift of signal sampling normally provides no problem for typical simulator measurements - as all signals are sampled within 16.3 milliseconds - a recording time accuracy which exceeds all known requirements to date. However, software can be provided which will account for the line by line signal sample time offset in plotting. The sequential sampling does provide one advantage; signal sampling rates greater than the 60HZ TV fixed rate are possible if the same signal is applied to two or more channels which are evenly spaced within the TV field. Thus, the system is capable of operating at a 120 or 240HZ sample rate, at the expense of the total number of channels available. To date, the 60HZ rate exceeds all simulator recording requirements.

## Data Review

Once recorded, the video data may be reviewed by test personnel in much the same way you would review film with a film editor. Video recorder controls allow bi-directional tape playback at a variety of speeds running from field by field stop motion to twice real time. Test directors may listen to the audio and watch the movement of dials, indicators, and bar graphs representing selected signal data. As they slew through the tape, they may also note the video field numbers appearing in the run data block. When a section of data of particular interest is located, the operator then need only note the field number appearing at the start of the data of interest.

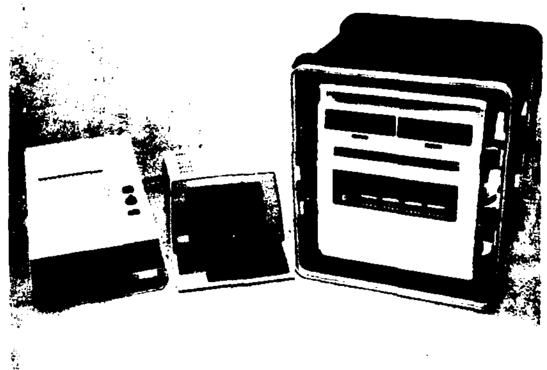

Figure 8

TI-990 Minicomputer with Dual Floppy Disk

Tektronix 4006 Graphics Terminal

Tektronix 4631 Hard Copy Unit

## Data Retrieval

The data retrieval system consists of a Texas Instrument TI-990/10 Minicomputer System, a Tektronix 4006 Graphics Terminal, and a Tektronix 4631 Hard Copy Unit. (See Figure 8) The computer is a 16-bit minicomputer configured with 32K words of memory and dual floppy disk drives. Automated data retrieval is initiated using the graphics terminal keyboard to enter the beginning field number and the time duration for the data of interest. The computer will then take control of the video recorder, search for the data of interest, and transfer all digital block signal data from the video tape to the computer memory. Data is then sorted by channel and stored on a floppy disk. The operator will then be prompted to select the types of plots required. The graphics package will co-plot up to six channels of time history recordings, or will cross-plot ($X-Y_1Y_2$) any three channels selected. See Figures 9 and 10 for examples of time-plot and cross-plot graphics. In each case, the plot packages will also label and scale the graphs using the run and channel labeling information entered prior to recording, and carried within the digital block. The hard copy unit will

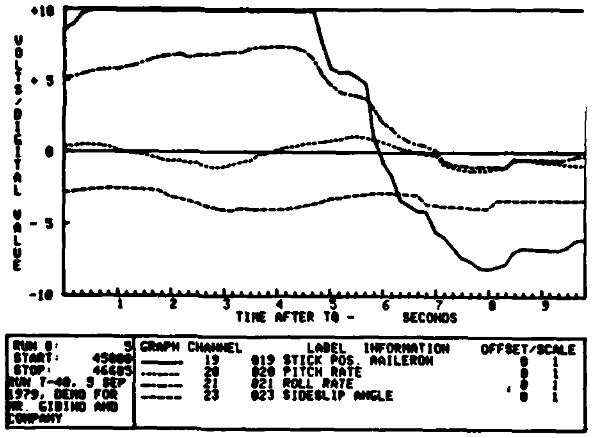


Figure 9 Time Plot

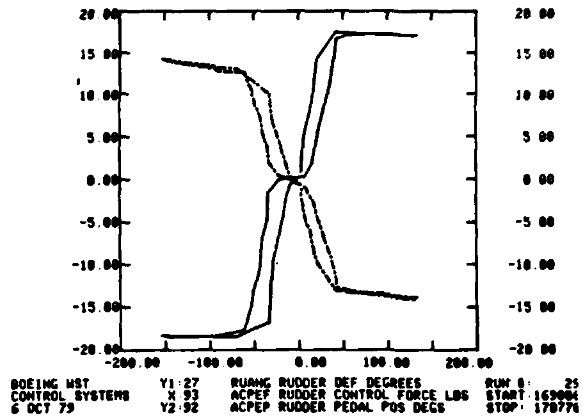


Figure 10 Cross Plot

reproduce all graphics. It is significant to note that the plotting package and retrieve software process only sixty data points (samples across time) for each of the 192 channels recorded. The plotting resolution of the graphics hardware cannot practically handle more than 60 to 100 data points. Thus, if a data retrieve of one second is desired the computer will transfer the plot values for each channel from every TV field recorded during the one second period (60). However, if a two second retrieve period/plot is required, the computer would process and plot data for all channels from every other field. A ten second retrieve would result in data being taken from every tenth field, etc. The system will retrieve and plot (on one sheet) data of any time interval from 1 second to 60 minutes using the sixty point sampling retrieve systems described above. Plotting of multiple 1 second graphs (most probably scotch taped end to end) is required in situations where <u>every</u> point recorded <u>must</u> be plotted. No simulator applications to date have required such plotting resolution.

<u>Data Analysis</u>

A very limited amount of data analysis capability has been provided as part of the SDTIS software. Four programs will be available. They are:

1. Software Filtering - A three pole butterworth filter is available and can be used to process any 60 point time history retrieved from video tape.

2. Accelerometer Translation - An accelerometer package location translation program is in development which will allow pilot seat acceleration to be taken from anywhere on the motion platform.

3. Six Post Motion Platform Conversions - Many simulators today are designed with six post synergistic motion platforms. These systems provide six degrees of freedom movement, but the axis of platform motion is usually the synergistic product of the movement of six hydraulic drives. All simulator computer software is structured to drive these six hydraulic cylinders, with signals which are easily recorded. However, review of the six post drive values tells one very little - what is desired are the resulting values of platform pitch, roll, yaw, and heave (x, y, z). Transformations have been developed for this conversion. Thus, the six post drive/follow signals can be used to produce time histories of platform motion which can be directly compared to other simulator flight performance parameters or aircraft data.

4. X-Y Position to Angle Conversion - Routines for plotting video tracker X-Y position outputs as a function of dial pointer angle.

Extensive data analysis is possible if the SDTIS is linked to a larger computer system with a modem. This will permit use of techniques such as Fast Fourier analysis which are generally beyond the capability of the SDTIS minicomputer. Software will be developed which will allow the SDTIS system to act as a data terminal to the General Electric Timeshare network. This arrangement should give simulator engineers the best of both worlds - independent data reduction to the maximum extent possible, coupled with the power of a large system when and where needed.

<u>Control Movers</u>

Previous sections of this paper have described the basic functions and design of the SDTIS - to sense cues, to record them, and to conveniently reproduce them as hard copy plots. However, the SDTIS (or any other instrumentation system) is incapable of fulfilling its intended "end to end" test roll without the ability to provide standard, controlled inputs for the simulator controls (stick and rudder). Comparison of cue time history data taken from run to run on the same simulator is not possible unless the control inputs (which caused the cues to be produced) were nearly identical. Even more significantly, comparison of simulator cue time histories with flight test data is not possible unless the simulator is flown under the same initial conditions, and with the same control inputs, as the flight test airplane. Such controlled, standardized inputs are not possible using human operators (pilots). Thus, we see the need for a family of control movers that are capable of:

1. Three axis dynamic control inputs
2. Making <u>standard</u> control inputs which are likely to produce known results (ramp, sine, etc.)
3. Reproducing aircraft control inputs as recorded by flight test instrumentation, and
4. Operating in either a position or force mode (force versus time or position versus time).

Figure 11 shows the yoke and rudder movers with associated controls and electronics designed for this purpose. Test and system integration of the movers is now ongoing. When fully integrated, the control movers will be driven by prerecorded control movement profiles which have been stored on floppy disks. Use of the movers will then complete our ability to perform a controlled "end to end" simulator system test. Figure 12 shows the yoke mover coupled to a control yoke. Note the force sensor located near the universal joint.

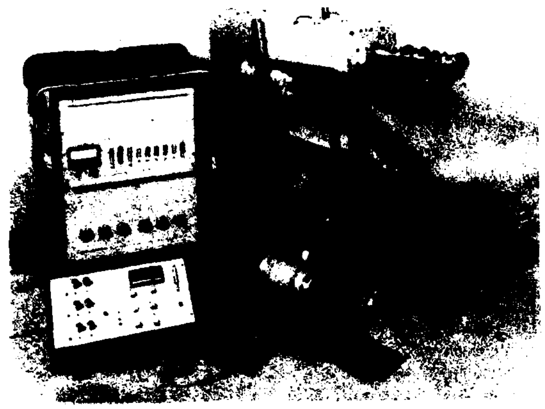

Figure 11

Control Mover Systems

(Yoke mover, Rudder mover and associated electronics)

This completes the description of the SDTIS. As illustrated in the photograph, all instrumentation hardware has been packaged such that it *"could be" shipped as airline* baggage by most carriers. However, the total system weight exceeds 2000 pounds. Air freight and truck are expected to be most often used.

Figure 12

Yoke Mover Coupled to T-40 Simulator Yoke

FUTURE SYSTEMS-DATA BUS ARCHITECTURE

The current design concept of the SDTIS does little to consider the internal system architecture of the simulator. Of course, point to point signal tracing is possible - and was, in fact, a design objective. However, as simulator systems evolve, we expect to see the current analog interface systems replaced with architecture wherein both control inputs and cue producers (instruments and displays) are connected directly to a digital data bus. Thus, the signal tracing function will largely be replaced by a data bus monitoring function. Such is already the case with much electronic warfare (EW) simulation. The ability to eavesdrop on data bus communications is essential to system test and troubleshooting. An extension of the SDTIS to encompass data bus monitoring is now in design for the EW task. However, the basic "end to end" test concept of the SDTIS will remain unchanged. It is interesting to note too, that as aircraft systems architecture follows the data bus trend, high fidelity simulation may be even more difficult to produce. Aircraft controls and display technologists are now considering hierarchal data bus structures, wherein data is processed (by asynchronous processors) and transferred from bus to processor to bus several times. Proper simulation of cue correlation/timing for such systems may indeed by a challenge.

CONCLUSIONS

Simulator Procurement Impact

SDTIS availability is expected to significantly impact the Air Force procurement of flight simulators. Trainer handling qualities tests are expected to transition from a largely subjective activity, to a largely quantitative one, although subjective evaluation of handling qualities will probably never be eliminated completely. Use of *SDTIS test procedures will* be written into future procurement specifications and the specifications themselves will be written in more quantitative terms than has been possible in the past. However, the degree of simulation fidelity achievable through use of SDTIS concepts is dependent on the degree to which the flight test instrumentation community can support simulator designers with high quality data. To date, the SDTIS has been used by the Simulator SPO for evaluation of both the Boeing and Singer B-52 Weapons Systems Trainers, and by the Air Force Flight Test Center for evaluation *of an F-4 Simulator at Moody AFB, Georgia.*

Flight Test Impact

Use of SDTIS concepts in simulator procurement is expected to expand significantly during the 1980s. Thus there will be a demand for flight test data required to support the high fidelity integrated aircraft system simulation discussed at the beginning of this paper. This will likely impact the flight test instrumentation community in the form of requests for data from more sensors located in or near the cockpit, which are correlated with data obtained from other aircraft systems (engine, airframe, etc.). For example, accurate dynamic recording of stick and rudder position and force correlated to instrument readings, throttle setting and flight dynamics will be extremely valuable. Likewise, recordings of vibration, buffet, and g-forces experienced by the pilot and correlated to other flight dynamics will be critical to development of quality, dynamic motion simulation. The nature of flight test data processing and massage may also be impacted. Complete time histories of control force or position may be needed in areas where only peak values were required before. This is illustrated by an example of pitch trim force. During level flight, when flaps are dropped, most aircraft will naturally assume either a pitch-up or pitch-down condition. The pilot must input some amount of control stick force to pull the nose back to straight and level. Aircraft specifications are usually concerned only with the peak stick force required to resume level flight. The only data which customarily shows up in the flight test report is that number - a single value. However, development of good simulation requires a knowledge of the complete stick force time history required to trim the aircraft. Thus, we can foresee a need for not only more data (from new sensors at additional locations) but also for expansions in reporting data that is currently recorded.

### Application of SDTIS to Flight Test

The current SDTIS hardware was not designed to fly (although it could probably be tested and certified for airborne use assuming an aircraft had space to hold it). However, techniques developed for the SDTIS may provide solutions to some problems of concern within the flight test community. Of particular interest should be the use of digital encoded video recording techniques. However, the SDTIS represents only one approach to exploiting a video technology that promises much capability at relatively low cost. Development of digital video sensors and recorders is now moving quickly due to the support of consumer and broadcast marketing interests. This work promises to yield future generations of advanced recording devices which may significantly surpass the capabilities of lesser developed recording technologies used conventionally for flight test instrumentation. The video techniques developed for the SDTIS should warrant serious consideration by designers of future flight test instrumentation systems.

## SUMMARY

Development of the Simulator Data Test Instrumentation System is nearly complete. The instrumentation hardware and the test methodology it supports represent an extremely flexible tool which may assist both government and industry in development of training systems which exhibit the performance fidelity required in the 1980s.

## ACKNOWLEDGEMENT

The SDTIS development is a product of the efforts of the engineers, technicians and co-operative engineering students within the Visual and Electro-Optical Branch at Wright-Patterson Air Force Base. The success of this system would never have been realized without their innovation and hard work. Much of the design and fabrication was accomplished through the voluntary contribution of overtime hours. I especially wish to recognize the efforts of Messrs Ronald Ewart, Steven Ingle, Edward Timko, Dana Hope, Joe Lucente, MSgts Gregory Finnie, James Loomis, William Ferrier, and 1Lt Craig Seymour. Their dedication and enthusiasm made the SDTIS possible.

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# AIRCREW INFORMATION REQUIREMENTS IN SIMULATOR DISPLAY DESIGN: THE INTEGRATED CUING REQUIREMENTS STUDY

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## ABSTRACT

Problems involved in the design of flight simulator displays have received insufficient attention. Simulator utilization and training problems have a basis in the design process. It is generally left to the simulator designer to use 'best judgement' in translating training requirements to display software/hardware specifications. At present, human factors data needed to accomplish this are either not available or simply not accessible in a form useful to the designer. Basic sensory and perceptual data, principles, and models exist or can be derived which could serve as a valuable resource for the designer in the specification of display requirements. The Integrated Cuing Requirements Study is a current Air Force sponsored effort to consolidate and publish these data in a format which will enable designers to rapidly access and apply this information.

## INTRODUCTION

"Psychologists should be able to say what needs to be simulated and engineers should be able to say what can be simulated."

"In the absence of guidance from psychologists, engineers can hardly do more than strive for realism limited by technical consideration and cost." (1)

In the past few years, the importance of simulation to aircrew training has greatly accelerated as have the engineering state of the art and relative procurement costs. However, relatively little advancement has been made in providing an objective basis for translating training requirements into aircrew training device specifications. Much of the process as it currently exists is dependent upon the subjective judgement of experienced simulator engineers in the absence of sufficient behavioral (i.e., sensory and perceptual) resource data. In fact, the driving considerations are frequently the most advanced equipment features that can readily be produced.

The Air Force Human Resources Laboratory, Aerospace Medical Research Laboratory, and Aeronautical Systems Division's Deputy for Simulators and Engineering Directorate have jointly sponsored a study directed at the exploitation of sensory and perceptual characteristics in the design of visual displays for aircrew training devices. Based upon this research, it is clear that sensory/perceptual data, principles and models do exist (or can be derived) which could assist simulator engineers in the design of cost and training effective simulators.

## DESIGN PHILOSOPHY AND PROCESS

### Systems Complexity

The primary purpose of a flight simulator is to synthesize information, relevant to the training and performance of piloting activities, that is normally available to the aircrew in the operational aircraft environment. This information is typically imparted to the aircrew member at the flight station via a synchronized array of visual, motion, and aural displays. These displays interface, in turn, with a variety of non-display components.

The basic components of a flight simulator typically include a flight station, visual display subsystem, acceleration and motion subsystem, control simulation subsystem, sensor simulation subsystem, instructional/experimental control subsystem, and computational subsystem. Each of these system components is further reducible to subsystems, assemblies, subassemblies, etc. (Figure 1). The Flight Station includes status lamps and indicators, radar/sensor displays, and flight instruments. The Visual Display Subsystem is interfaced with the Flight Station to provide a through the windscreen view of the external flight environment (2). The Acceleration and Motion Subsystem simulates the non-visual environmental forces which act upon the aircrew member in operational aircraft. The feel of the controls, mimicking environmental forces such as aerodynamic loading of the control surfaces, is displayed via the Control Simulation or 'Control Loading' Subsystem.

Interactions occur among components and/or levels of a given subsystem as well as between individual subsystems (Figure 1). These interactions must be anticipated and specified in the design process prior to the actual integration of these components into a functional simulation.

Design Process

It is the critical task of the simulator designer to translate training (or research) requirements into display system/subsystem specifications. Training requirements are identified and reduced by task and cue analyses into simpler behavioral elements. This task/cue analysis results in the specification of aircrew information requirements which, in turn, is expected to lead to a specification of what must be displayed (i.e., content), and the necessary characteristics of the display (i.e., quality and format). These must then be translated, by the designer, into simulator system/subsystem specifications.

The problem is that in actual practice there is insufficient information available to the designer to enable this logical and orderly design process to work. It is left up to the designer to use his 'best judgement' in those areas where data are lacking. Typically, design decisions are made on the basis of a phenomenological integration of a set of variables that are not necessarily optimal in terms of satisfying training requirements (Figure 2). These include the state-of-the-art technology, past approaches, cost/performance trade-offs, management constraints, and human factors guidelines to the extent that they are available in a useful format.

Design Philosophy

As can be seen from Figure 2, critical decisions made in the design process are based on the subjective integration of a range of variables by the system or subsystem designer. In the absence of sufficient hard data, the designer must make some basic assumptions about what information is necessary to satisfy training requirements, the approach to portraying that information (i.e., display content) and the necessary quality and format of the display.

Typically, the approach to simulator design has been to provide as much of a linear equivalent of the real world (i.e., realism) as the state-of-the-art technology will permit (3). This of course is done with the expectation that satisfactory compliance with training requirements is positively correlated with apparent realism (4). In other words, if a simulation looks, feels and sounds like the real aircraft, then the basic requirements for training should likewise be present. The design engineer can hardly be faulted here since he gets his direction from a customer (the operational user) whose criteria for acceptability is based upon the degree to which the ground based simulated environment approximates his perception of the 'real' flight environment (5).

Implementation of this maximum realism approach has fallen considerably short of its ideal (i.e., an objective simulation of the flight environment). As evidence of this, the most advanced computer generated visual displays are, at best, low fidelity representations of the real world. These typically appear cartoonish and deficient in fine detail. In motion simulation, platforms are pushed to their maximum excursion (within facility constraints) so as to display the aircraft motion environment with as much realism as possible before commencing washout. Regardless of these attempts, motion displays are beset with false motion information which is inconsistent with the aircraft motion environment. Additionally, there are numerous instances of spatial/temporal asynchrony between the visual and motion display modes. In sum, there exist many examples of what we call errors of omission, inclusion, and synchronization that detract from the realism of the display.

Errors of omission generally refer to those spatial/temporal details that may be lacking in a display which detract from apparent realism. Visual errors of omission include limitations in texture, density of scene content, size and continuity of the visual field, aerial perspective, resolution and directional illumination (shadows). In motion simulation, these include high-G loading and sustained motion.

Errors of inclusion are those artificial features or details unique to the simulation that are not commonly found in the 'real world'. Errors of inclusion for visual displays include saturated colors, level of detail switching, visible raster patterns, and stylized scene components that tend to be uniform in shape or distribution throughout the display. Similarly, in motion displays there are anomalies related to motion washout and to equipment limitations (e.g., 'hydraulic bump').

Errors of synchronization refer to spatial and/or temporal phase lags within or across display modes. These include delays and/or conflicting information among control interface, visual, and motion systems.

It is important to emphasize that these errors are errors only in that they depart from the intended realism of the display. The actual effects that these have on performance vary widely and are in need of further study. However, negative effects have been documented ranging from temporary distractions to which a pilot quickly adapts (6) to incidents of severe psychophysiological distress (7). On the other hand, planned distortions or manipulations of the visual scene have been shown to enhance performance in the flight simulator (8,9). Several studies have reported positive effects on training or performance by systematically augmenting the information available to the pilot in the simulated visual scene in order to facilitate the acquisition of task critical information (10,11).

Another more recent approach has been to tailor display specifications to the information requirements of the aircrew member. Presumably this would enable the optimal allocation and prioritization of technology constrained display resources. A major problem is that at present there are no reliable or comprehensive procedures for determining information requirements for the training or performance of specific aircrew activities. While it is possible through task/cue analyses (including geometrical analyses of the task environment) to define the information available to the aircrew to support the realism approach, it is not well understood which information is in fact relevant given the aircraft system, environment, mission, and a host of individual variables relating to the aircrew member and his previous training. Hence, given the current state of knowledge, it remains for the designer to bridge the gap between training requirements and information requirements. In the absence of sufficient guidance from psychologists, the designer has no choice but to use reality as his metric.

Once the designer has made these decisions regarding display information requirements, he must decide how this information should be represented in the display. Unfortunately, there is no objective methodology for generating pictorial scene requirements from visual information requirements (11,12). Here, once again, the designer is called upon to use his best judgement based upon a subjective integration of variables (Figure 2) that are not optimal for satisfying the aircrew member's perceptual information requirements.

## USE OF SENSORY AND PERCEPTUAL DATA AS A DESIGN RESOURCE

Once the designer has established what is required and how it should be portrayed, it still remains for him to specify the parameters of display quality, format, and configuration relative to the total system. The issues of display quality are essentially information management issues. One approach to effective display management of aircrew information requirements is to capitalize on human sensory and perceptual capabilities and limitations.

The sensory and perceptual data are specifically germane to the needs of the simulator engineer or designer. These data provide functional relationships for the variables that influence the acquisition and processing of information as well as perceptual motor control output (13,14). For example, in determining the information requirements for an 'out the window' target interception task:

a. The information acquisition or sensory data describe the variables which influence target detection (e.g., luminance, contrast, target size).

b. The information processing or perceptual data describe those variables which impact identification of the target (e.g., perception of size, distance, motion).

c. The perceptual motor control data define the variables which influence the manual control of the aircraft while tracking the target.

When used appropriately, these data can be a valuable resource for:

1. Developing specifications based on sensory or perceptual characteristics (i.e., matching simulator display characteristics to human sensory capabilities). For example, it should not be necessary to simulate a specific force of 0.01 G since this is, under most conditions, below the threshold of detectability.

2. Evaluating specifications or prioritizing design options. Many existing specification requirements and industrial standards do not have an empirical basis for their existence. The sensory and perceptual data can be a valuable resource for their evaluation. In addition, past attempts to achieve realism have resulted in spatial/temporal distortions which could have negative impact on the acquisition or processing of cue information. The sensory and perceptual data can provide a basis for evaluating this impact. More importantly, capitalizing on the information processing data might provide a basis for alternatives to realism.

3. Generating new design or training alternatives. Data from Regan, Beverley, and Cynader (1979;15), Regan (1980;16), Ginsberg (1980;17,18) and others suggest that specific sensory capabilities may be enhanced through special training procedures. This portends a new approach to pilot training as well as a new generation of training devices which are geared toward improving the pilot's 'natural' ability to acquire and process information.

When used appropriately, the sensory or perceptual data can be an effective resource to the experienced engineer and designer. However, there are limiting factors to the value of these data. Specifications suggested by these data may not be practical in terms of technology or cost. In fact, in many instances current technology cannot match the limitations of human perception. As an example, consider the situation in Computer Generated Imagery wherein the displayed image of a light source is decreased in area as the square of the calculated viewing distance so as to provide a change in retinal image size that conforms with normal visual experience. The displayed image cannot be reduced below one pixel which, for most displays, subtends an angle two to four times larger than the optimal resolution limit (19).

Appropriate implementation of these data requires that they be integrated with other factors by the experienced engineer and designer (as shown in Figure 2) to yield final requirements or specifications.

Furthermore, much of the data regarding human sensory limitations and perceptual capability are either not yet known or have not been sufficiently well defined to enable their direct translation to engineering applications. Where data are known, they are usually not readily accessible in a form useful to simulator designers (20,21,22). It should be noted, however, that where visual sensitivity data have been accessible to designers (23, 24), they have been successfully exploited in the specification of visual displays (25).

The Integrated Cuing Requirements Study is a Research and Development program under contract to

The Boeing Aerospace Company (Seattle WA) to exploit sensory and perceptual characteristics, principles and models useful to the design and specification of simulator displays. The technical objectives of this study are:

1. To identify, collect and consolidate basic sensory/perceptual data germane to training and engineering requirements. This will be documented as a data base organized around principal areas of sensation and perception. It will contain a minimum of text but will instead concentrate on detailed illustrations, quantitative functions, characteristics and models.

2. To develop specialized information retrieval techniques to facilitate the accessibility and application of these data by design engineers. These will be documented as a User's Guide which will lend structure to the Data Base in accordance with the needs of simulator designers. It is also feasible to develop User's Guides to the Data Base for other user populations for whom these data could be a resource (e.g., human factor engineers).

In summary, the Integrated Cuing Requirements Study will, in itself, provide a valuable resource to design engineers. However, optimal implementation of this resource to training simulator displays is wholly dependent on also developing the ability to specify: (1) the information necessary for effective training of specific aircrew tasks, and (2) the optimal way of portraying this information (i.e., levels of abstraction or realism). A research effort which systematically responds to these basic questions is critical to the design of training effective flight simulators.

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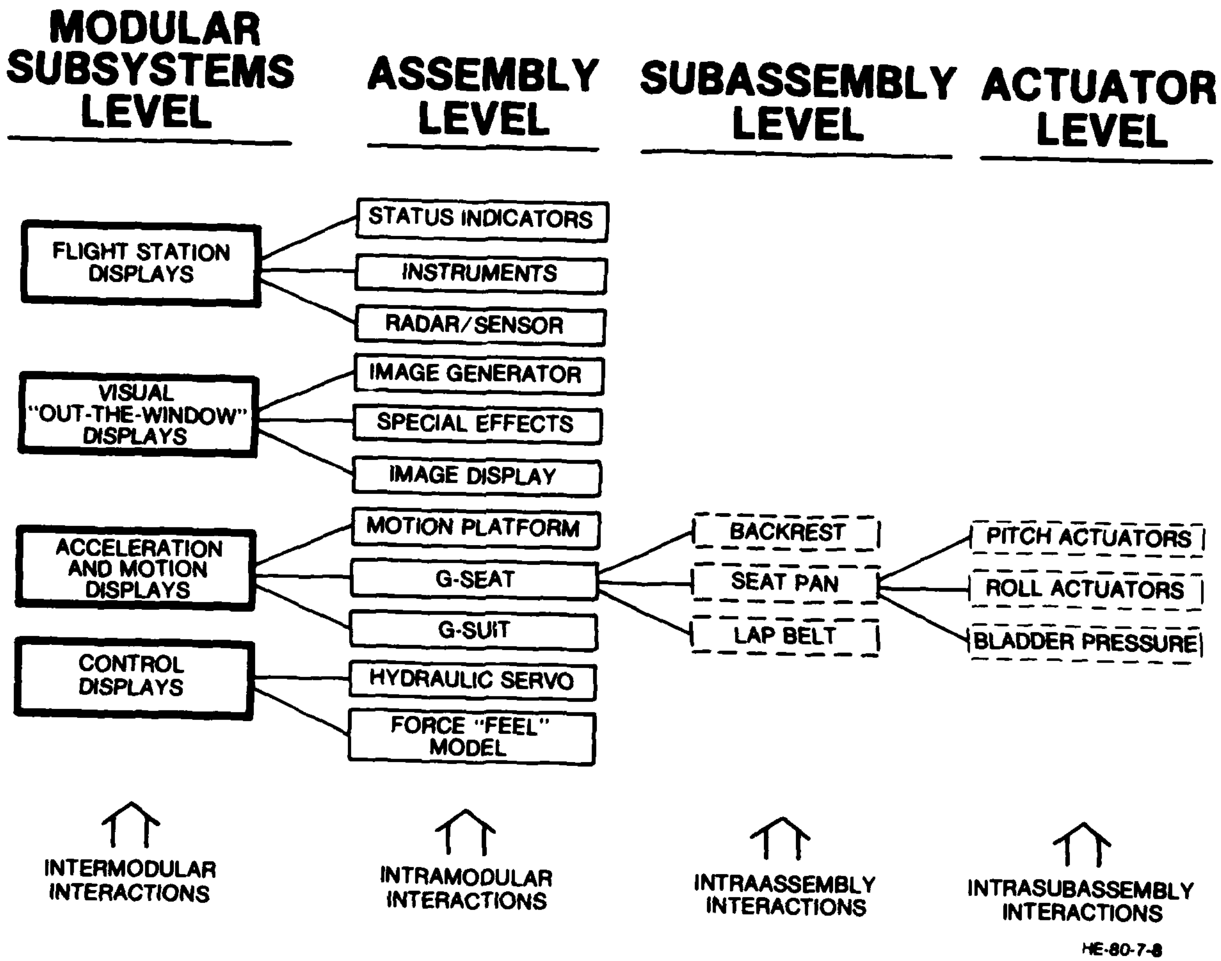


*Figure 1. Simulator systems complexity.* Each system is reducible to subsystem levels. Interactions may occur among components and/or levels of a given subsystem as well as between individual subsystems. Reduction of subsystem components below assembly level is shown for the G-seat only.

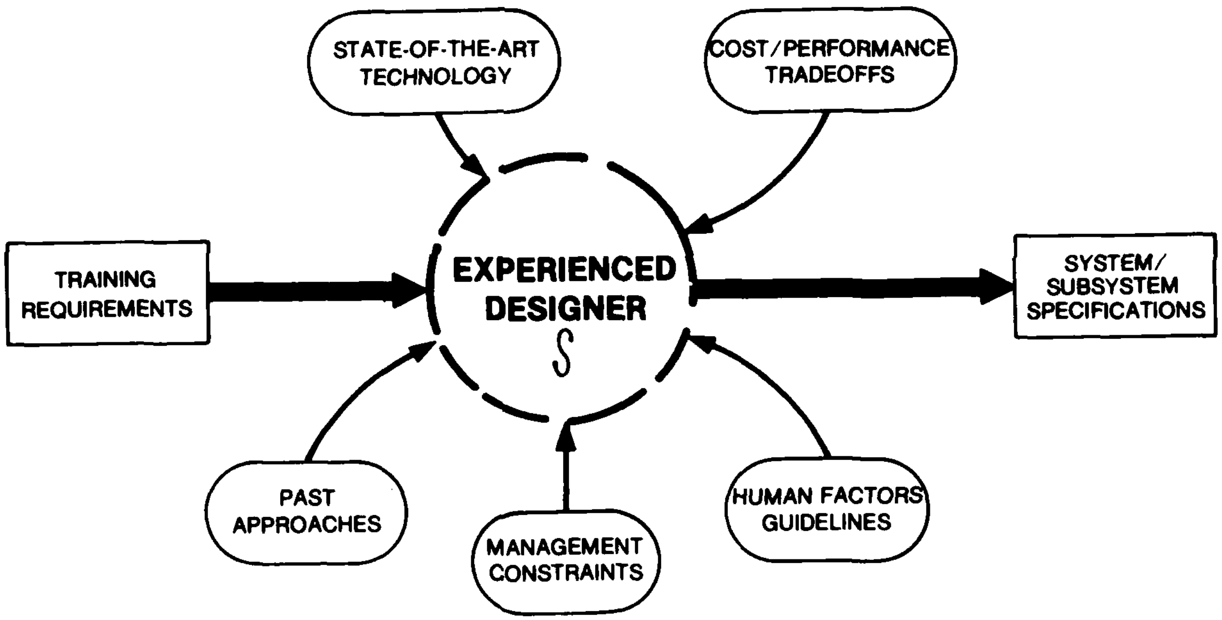


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Figure 2. Design decision process. Design requirements and specifications are determined by the subjective integration of a range of variables.

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# ASPT G-SEAT/G-SUIT OPTIMIZATION

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## ABSTRACT

Research was conducted to optimize, in terms of both hardware response and software driving philosophies, the effectiveness of pneumatically operated g-seat and g-suit flight simulation subsystems for high performance aircraft, such as the Advanced Simulator for Pilot Training (ASPT) F-16. Results indicate that drive philosophies should be a dynamic function of g-range, ground or air operation, maneuver, and task. In some cases logical and satisfactory philosophies for T-37 training were improved by reversing their effect for high g maneuvers.

## INTRODUCTION

The G-seat is a flight simulation device designed to induce body position and pressure manipulations, controlled according to a programmed drive philosophy, so that acceleration sensations may be perceived by pilots. The typical pneumatic G-seat system consists of a seatpan with 16 active air bellows, a backrest with nine active bellows, thigh panels with six active bellows, and an active seat belt.(4) Each of the 32 items is individually controlled via pneumatic hoses leading from the pneumatic control components to the seat elements. The 32 pneumatic devices are in turn governed by a G-seat computer program within the simulator's computational system.

### Background

The Advanced Simulator for Pilot Training (ASPT) G-seat was developed by Singer-Link to be used in conjunction with a T-37 flight simulation. As such, it was designed for sustained G-cueing during basic airwork and aerobatic flight typical of training aircraft. The ASPT force-cueing philosophy was to provide onset acceleration cues with a six degree-of-freedom platform motion system followed by blending in the G-seat cues to sustain the acceleration effect as the motion system cues were "washing out". The original software was based on the geometry and characteristics of T-37 aircraft; however, the seat was also designed as a research device with a high degree of flexibility in order to investigate the simulation of tactile, pressure, and skeletal posture cueing resulting from flight-induced body G-loading.

### Purpose

Although advantage could be taken of this flexibility in configuring the G-seat responses to other aircraft characteristics, it was also necessary to improve the response time of the system to effectively simulate the G-cues of higher performing F-16 aircraft. In addition it was felt from the early sensory mechanism modeling work that the G-seat could be an effective onset cueing device. Since the G-seat interfaces with the most responsive sensory mechanisms, the tactile and pressure receptors, it can be argued that it should be designed as the most responsive of the G-cueing devices. A highly responsive hydraulic Advanced Low-Cost G-Cueing System (ALCOGS) was under development but was not available for use in the ASPT F-16 project.(3) However, an improved G-seat, perhaps capable of onset cueing, was felt to be essential to satisfy the motion and force cueing requirements of high performance F-16 aircraft.

## APPROACH

Provision of a high performance G-cueing capability for the ASPT was divided into three phases:

Phase I: The objective in this phase was to establish the nature of the response lags in the pneumatic G-seat system and to minimize those lags by optimizing the hardware configuration and the software execution. Another objective was to provide a more usable and understandable program which would facilitate determination of the most effective drive techniques under the following phases.

Phase II: The objective in this phase was to determine the most effective software drive techniques and philosophies under the optimized response condition of Phase I.

Phase III: The objective in this phase was to attach and evaluate new G-cueing devices (such as air bladders based on the Advanced low-cost G-cueing design) and develop new sustained drive techniques. The improved response time of Phase I also made feasible the development of special effects, such as runway rumble, stall, constant, airframe vibration, gear effect, and other buffets.

This paper summarizes the Phase II and III efforts. Phase I is fully documented in Ref (1), but a summary of the hardware optimization portion of Phase I results are that the response time could be decreased by as much as half (350ms to 150-200ms) by the following modifications:

1) Moving control valves to the platform to reduce hose length.

2) Using larger inside diameter hoses.

3) Relocating needle valves from the input to output of booster valves.

4) Resetting needle valve and booster valve controls.

The software optimization portion of Phase I resulted in a more organized and flexible program which was used to vary the drive philosophies of each G-seat component. For the Phase II and III, the ASPT G-seat was considered to contain the following components: seatpan, backrest, thigh panels, lapbelt, and air bladders;

Responding to the following drive inputs:

X-axis acceleration
Y-axis acceleration
Z-axis acceleration
roll velocity or roll acceleration
special effects conditions;

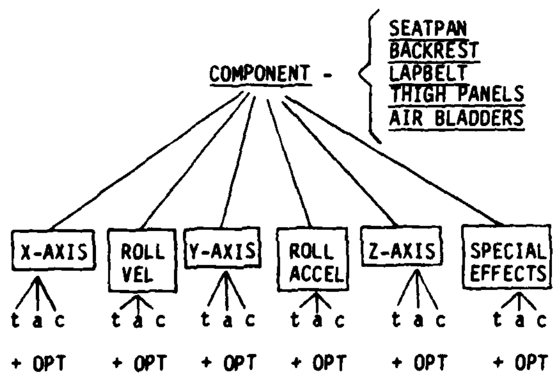
Under the following concepts:

<u>Translation</u>: The elevation of a complete set of cells caused to translate in unison a uniform distance.

<u>Orientation or Attitude</u>: The plane formed by a complete set of cells is caused to be reoriented.

<u>Contouring</u>: A set of cells caused to assume a contoured shape which produces a flesh pressure redistribution thought to be compatible with body response to acceleration.

<u>Special Effects</u>: Bumps, vibrations, buffets, or other special responses.




t = translation
a = attitude
c = contouring

Options Included: Acceleration distortion, combinations, modification of basic logic, deadband, etc.

FIGURE 1 - Research Approach

Attenuators were placed upon each axis response; for each drive concept; and for each component, except where clearly not applicable (e.g. contouring for lapbelt). The attenuators were then used to increase, decrease, or reverse any specific response based on axis, drive concept or component.

Due to the numerous possible combinations of accelerations, axes, drive concepts and components, it was decided to use subjective pilot feedback as the only criteria for developing the drive techniques. In addition to the convenience of this method, it was felt that any other analysis would be too time-consuming and eventually subject to pilot approval as the final judge of its effectiveness.

All components, drive concepts, or axes not currently being investigated were deactivated in order to isolate the effects. Once a valid response was developed, another axis, drive concept, or component was added and adjusted until it either contributed to the effect or its possibilities were exhausted.

In conjunction with this basic response investigation, all other options of the driving philosophy were exercised such as the distortion logic (non-linear response), deadbands, combinations of accelerations, and occasionally modification of the basic controlling software logic or addition of options. If an improvement was not determined and the drive did not present a negative cue, it was returned to its original state or value. The final product thus contains some improved and effective drive logic, some original and effective drive logics, and some original ineffective drive logic. It was felt that selective deletion of ineffective capabilities for certain axes or components would not significantly improve the G-seat and would tend to make it less flexible for the Phase III research.

## PHASE II - DRIVE PHILOSOPHIES

### Seatpan

The first component investigated was the seatpan. Translation response in the Z axis was experienced by the pilot for both negative and positive G's. The computer program uses negative G's as an indication of pullouts and positive G's as an indication of pushover (this is the opposite of the normal pilot terminology). The usual response of seatpan deflation on pullouts (position cue to simulate sinking into the seat) was valid, but the pushover response was preferred reversed so that the bellows also deflated upon pushover for a correct pressure cue. The pilot felt that when this was coupled with a relaxation of the lapbelt, an initial floating effect was generated. Thus, the seatpan has the same initial response (deflation) whether positive or negative G's are imparted. The difference is in lapbelt response: contraction on negative G's; relaxation on positive G's (pressure cues). At approximately zero G's, the belt drive reverts to that of contracting upon additional positive G's (position cue). The Z-axis contouring arrays (to simulate pressure distribution changes) were also modified to

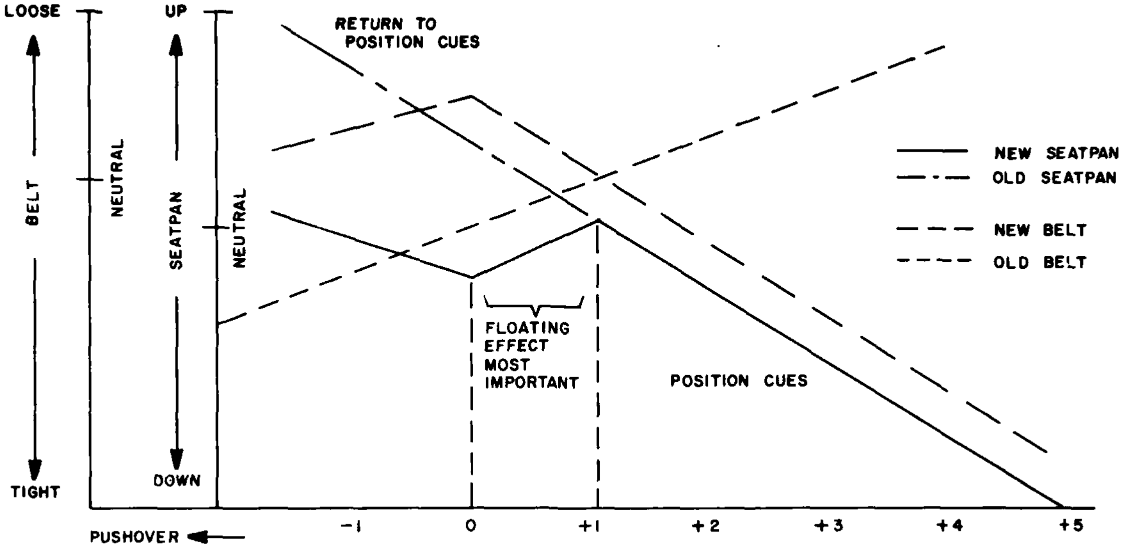



Figure 2 - Drive Optimization

correspond with the new philosophy.

Attitudinal response in each axis drive mode and option was experienced and modified if necessary. The most significant result is that a plannar response to roll cues (based on a driving input of roll velocity rather than acceleration) which simulated a tilting plane was effective rather than using the contouring arrays as originally designed. In the contouring concept some bellows do not deflate to the same degree as others causing a localized pressure increase or decrease (redistribution of body weight). Y-axis contouring was consequently not used.

The Y-axis attitude response to Y acceleration as a driving input should vary in magnitude, depending on whether the aircraft is on the ground or in the air. However, if a roll condition exists, the Y acceleration attitude drive is disabled (i.e., an attitude response to Y acceleration exists only if an attitude response is not required for a roll cue).

## Lapbelt

The normal drive of the lapbelt is to contract on pushover and release on pullout (to simulate the position cue of the pilot sinking away from belt). Upon reversal, however, the lapbelt tended to enhance the sinking into seat sensation by increasing the buttock pressure imparted to the pilot. The lapbelt apparently distributed the pressure over a wide enough area so that the main effect was felt through the seat-buttock interface rather than the belt-abdomen. It was also confirmed that the addition of a G-suit system would aid in distributing any localized lapbelt pressure. Figure 2 shows the original and optimized response of the lapbelt and seatpan for pushover and pullout maneuvers. Note that the seat drive reverses philosophy at the 1-G level, while the lapbelt does not reverse until the zero-G level. Software was installed to vary the slope before, after, and within the "floating effect" area and to vary the bounds of each area for each component. This was implemented by the following technique for the seatpan, lapbelt, and contouring.

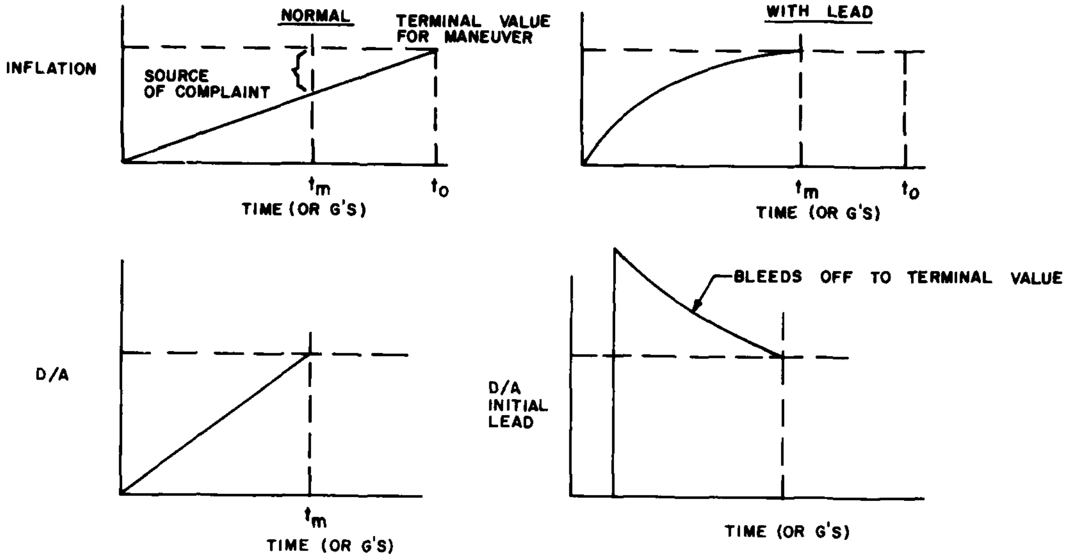
```
IF(Z.GT.1G and Z.LT.P2) SLOPE=A
IF(Z.LE.1G) SLOPE=B
IF(Z.GE.P2) SLOPE=C
IF(Z.GE.P2) CORRECTION=A*(P2-1G)-C*(P2-1G)
RESPONSE=SLOPE*Z+CORRECTION
```

Where:

1G : 386 in/sec$^2$ (neutral)
P2 : Acceleration levels where drive parameters (slope) may change values

CORRECTION: Necessary to maintain continuity when switching parameter values since excursions are based on total acceleration (sustained drive type) rather than deltas

Below neutral 1G (pullout maneuver) the seatpan deflates to create a sinking sensation (position cue) but the belt contracts to increase perceived pressure cues. Between neutral (1G) and zero G, the seatpan and the lapbelt apply pressure (i.e. less pressure) cues in order to simulate the important sensation of floating; the seatpan deflates to also decrease pressure and the lapbelt relaxes to decrease pressure. The conflicting position cue of sinking into the seat is apparently overriden by the pressure cue of the floating sensation. Beyond a certain acceleration level (zero-G) the lapbelt returns to providing a position cue (pilot floating into belt) and the seatpan returns to a position cue (raising pilot out of seat). The conflicting position and pressure cues here (pressure from rising seatpan; position from lapbelt) is minimized by a reduction in the slope of response. In addition, this flight regime is seldom experienced for any length of time.




$t_m$ = TIME THAT MANEUVER REACHES FINAL G LEVEL
$t_o$ = TIME THAT SUIT REACHES PROPER INFLATION FOR TERMINAL G LEVEL

Figure 3 - G-suit Optimization

## Backrest

The backrest response to y acceleration was also changed to a planar type and the y-contouring deleted. In addition, the best parameter values for response on the ground was found to be different from those in the air. This need was satisfied by basing the change in parameter values on whether there was weight on whee's (WOW) and an X acceleration. The value was replaced to a ground value whenever WOW was "true" which tended to provide a touchdown bump as the cells responded to the new parameter. However, a similar but inappropriate bump would occur on takeoff. The switch from ground to air values occur only when WOW is "false" and the X acceleration is near zero. In this case no bump will occur upon switchover since the cells will be at their neutral position.

## Other Modifications

Roll velocity was selected as preferable over roll acceleration as a driving input. Although a few exceptions were noted, the G-seat performed better with a roll velocity input for the majority of typical maneuvers.

Deadbands were preferred on the X axis roll velocity, and roll acceleration drive inputs which were independently adjustable for positive or negative magnitudes.

## Thigh Panels

Similar investigations for the thigh panels component were generally unsuccessful in that a drive philosophy could not be developed which was acceptable. The thigh panel did not provide any cue analogous to actual flight maneuvers. As a result, the thigh panels were deactivated. This also made air sources conveniently available for attachment of devices under Phase III.

## PHASE III - NEW DEVICES, SPECIAL EFFECTS AND NEW DRIVE TECHNIQUES

## G-Suit

A G-suit system was added to the F-16 simulation, but pilots occasionally commented about a relatively low rate of G-suit inflation. This led to the following lead logic scheme for improving the typical inflation without incurring over-inflation in maneuvers of higher G-levels.

The lead function is to command the controlling valve to open wider and thus inflate the suit higher in a shorter time. The D/A lead needs to be a function of not only the G-level of the aircraft, but also of the time that the G-level has not been achieved; i.e., the command should bleed off rapidly enough so that the suit does not actually overshoot the desired inflation level. A deadband is also necessary to prevent instability. The lead logic would otherwise tend to be frequently triggering and never bleed off completely.

The D/A initial lead command is limited for triggering at higher G-levels so as to not actually overshoot desired inflation levels. The G-suit logic is deactivated when landing (gear down) to prevent inappropriate triggering.

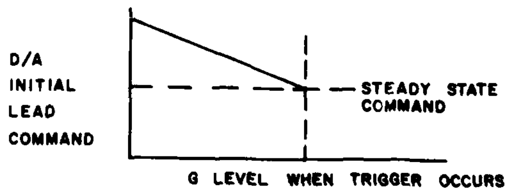



Figure 4 - Lead Control

The slope of the lead factor vs G-level was made variable along with the limits in order to determine the proper constraints. Lap belt and seatpan parameters were also adjusted to complement the g-suit cues.

Helmet Loader

In high performance aircraft, the G forces on the pilot's helmet provide important feedback concerning the aircraft's dynamic state as well as limiting the pilot's ability to move his head when the G forces are high. A helmet loader has been designed by Mr Bill Ashworth and Mr Alton Hall of NASA/Langley to provide the effects of these forces in aircraft simulators.(2) The design is such that the forces applied to the helmet are independent of the pilot's head/shoulder position and require only two strings to be attached to the helmet through pulleys attached to the shoulder harness. A secondary effect is provided through a loosening of the harness straps as force is exerted downward on the helmet (thus upward on the pulleys) for positive G. A prototype helmet loader was loaned from NASA/Langley for use in the ASPT/F-16 project.

The pilots did not have access to their own helmets during the studies which probably contributed highly to individualistic and conflicting ratings of the helmet loader. A summary of pilot comments are:

- Rotation of head restricted under g loading (although some thought this was realistic.
- Otherwise no restriction of normal movements
- Could positively affect performance (based on opinions)
- Single most overriding comment: Not enough force (approx 10 lbs)

Thus a system capable of safely applying higher forces, without restricting head rotation, and permitting use of personal helmets may be an effective high-g cueing device.

Air Bladders/Plates

Air bladders and overlay plates had been manufactured during the Advanced Low-Cost G-Cueing System (ALCOGS) development and used to simulate the ALCOGS design on the penumatic ASPT g-seat.(1) This research had established that the bladders and plates provided a more integrated, continuous sensation of a seat structure than the original ASPT design.

Due to the ineffectiveness of ASPT's thigh panels, the panels were removed and 4 unit air bladders for the seatpan and a 2-unit backrest were attached to those hoses. The control valve settings were adjusted to reduce the pressure range from 0-6 psi to approximately 0-2 psi. An overlay plate was placed over the 16 seatpan cells. Thigh wedges and tuberosity blocks were installed on the plate to provide the contouring concept. The air bladder was installed over the entire assembly with layers of foam separating each level (between bellows and plate, plate and bladder, bladder and seat cover).

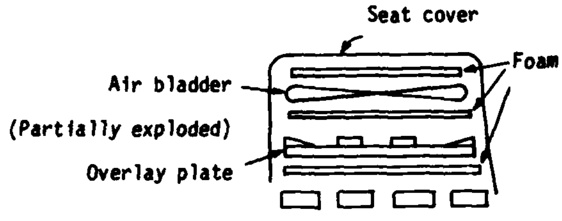


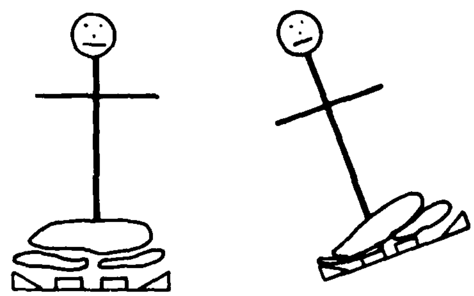

Figure 5 - ALCOGS Concept

The relevant thigh panel longitude, lateral, and vertical drives were altered to reflect their use as the appropriate bladder driving logic.

A weight bias was used in order to insure that the pilots tuberosities rest just above the plate at neutral. Otherwise, a conflicting cue may exist upon deflation and before contact with the plate.

The air bladders act supplementally to the orientation drive and translational drive of the normal ASPT seat replacing the pressure redistribution function of "contouring" and provide some position cueing as well. The previous contouring drive was deactivated since the overlay plate prevented the pilot from contacting the individual bellows of the ASPT G-seat.

In case of a pullout, the seatpan now deflates to supply a position cue; all four units of air bladder deflate to bring the buttocks into contact with the thigh panels and tuberosity blocks; and the lapbelt contracts to enhance the increased pressure effect. In a roll the seatpan acts as a plane and rotates, and one side of the bladder deflates to increase pressure sensation on the appropriate thigh.



Y ACCEL OR ROLL

Figure 6 - Air Bladder Use

Special Effects

In the optimized configuration the ASPT g-seat was capable of providing a coordinated vibration effect up to at least 15 Hz. Although it could accomplish only a small portion of the commanded magnitude (i.e. 15 Hz was well beyond its bandpass capacity of approximately 2-3 Hz) the existing excursions were more than sufficient to provide satisfactory special effects and in some cases had to be reduced from the maximum possible.

A general vibration logic was developed as follows:

Basic Magnitude (MAG) Calculations

```
COUNTER=COUNTER+1
IF (COUNTER.LE.FLAG) MAG=MAG+VIBMAG
IF (COUNTER.GT.FLAG) MAG=MAG-VIBMAG
MAX=2.*FLAG+1.
IF (COUNTER.GE.MAX) COUNTER=0.
```

The counter is incremented upon each computer pass (30 times per second). The magnitude was adjustable through VIBMAG and the frequency adjustable through FLAG as follows:

| FLAG | FREQ |
|---|---|
| 0 | 15.00 Hz |
| 1 | 7.50 Hz |
| 2 | 5.00 Hz |
| 3 | 3.75 Hz |
| 4 | 3.00 Hz |
| 5 | 2.50 Hz |

Where FREQ=15/(FLAG+1); 15 is the max frequency, derived from the computational rate of 30 iterations per second and 2 iterations reguired for one complete cycle.

The vibrational frequency and magnitude was varied throughout a wide range to determine the best technique for simulation of constant airframe vibration, speedbrake, gear effects (down, in-transit, and bump), runway rumble, and stall.

The results were as follows:

| | FREQ |
|---|---|
| Constant Airframe Vibration | 15.0 Hz |
| Speedbrake Buffet | 5.0 Hz |
| Runway Rumble (varies) | 7.5 Hz |
| Gear Bump | NA |
| Gear Down Rumble | 15.0 Hz |
| Gear In Transit Rumble | 15.0 Hz |
| Stall Buffet | 3.0 Hz |

These results were specific to this simulation, choice was limited to the available frequencies and could vary based on the aircraft simulated and the system characteristics.

Thus, at least a 30 Hz iteration rate is desirable for simulation of speedbrake buffet (15/3), constant airframe vibration (15/1), gear down rumble (15/1), and gear in transit rumble (15/1).

Touchdown bump effect within the seatpan was added with the magnitude of the bump as a function of how fast the aircraft approaches the runway in the Z-axis.

## Final Touches

Attitude response sensitivity was made a function of landing mode (gear down) where higher sensitivity was desired as a flare/landing cue. Similarly, the deadbands were decreased and special effects generated (gear buffet, bump) based on whether the gear was "not up and locked." The deadbands were also based upon whether a positive or negative acceleration maneuver was being performed. The following table summarizes the sensitivity of components or effects based on flight conditions.

| | G/A | LANDING | G-LEVEL | ROLL |
|---|---|---|---|---|
| Seatpan | x | x | x | x |
| Backrest | x | x | x | x |
| Lapbelt | | | x | |
| G-suit | x | x | x | |
| Bladders | x | x | x | x |
| Deadbands | x | x | x | |
| Special Effects | x | x | | |

## Conclusions

A pneumatic g-seat can be effective as a motion/force cueing device for high g, high performance aircraft provided the response time is optimized over the typical configuration, more effective components/concepts are used, and the driving philosophy somewhat dynamic based on the flight conditions or maneuvers being performed.

Additional improvements in response time and bandpass can probably be achieved only through a design change in the controlling valves and/or closing the system with feedback (position preferred over pressure since proper excursion is the objective); but a fully optimized pneumatic g-seat may have the potential to provide effective onset cues (currently attempted by 6 DOF motion system) as the most responsive of the force-cueing devices.

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# REAL-TIME DIGITAL SIMULATION OF AIRCRAFT FOR TRAINING APPLICATIONS: PAST, PRESENT, AND FUTURE

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ABSTRACT

The early use of special purpose analog computers in flight trainers faced many problems. These difficulties along with the recognition that the then emerging digital computer technology might be applied to training systems led to investigations of this area. The purpose of this paper is to trace the research and development of high-speed digital computers for real-time operations in solving the flight equations in real time through the current state-of-the-art digital systems used in flight trainers. Three basic aspects of real-time digital computer systems for flight trainers are reviewed; namely, computer system architecture, iteration rates required, and programming. In addition, a forecast of future systems architecture and programming concepts based on research currently underway is offered.

## INTRODUCTION

Early attempts made to utilize digital computer technology in the solution of flight equations in real time faced many problems. The purpose of this paper is to trace the research and development of flight trainers utilizing high-speed digital computers for real-time operations in solving the flight equations through the current state-of-the-art digital systems used in flight trainers. Three basic aspects of real-time digital computer systems for flight trainers will be reviewed; namely, computer system architecture, iteration rates, and programming. In addition, a forecast of future systems architecture and programming concepts based on research currently underway is offered.

## INITIAL CONCEPTS AND DEVELOPMENTS

Immediately following World War II, the Office of Naval Research, then the Office of Research and Invention, undertook the development of a number of computer systems (1). The Whirlwind system was a digital computer development whose initial objective was to simulate the flight envelope of an aircraft to obtain pilot evaluation of proposed aircraft based upon wind tunnel data before going to the expense of developing a prototype (2). Although it did not meet its basic objective, it did result in a very powerful computer for its day. However, the scientific and engineering applications of the digital computer led to a more rigorous mathematical description of the equations of flight.

The flight trainers developed by the Armed Services in the late forties called for the solution of the differential equations of motion using analog computer systems (3) (4). However, difficulties were experienced in the development and use of analog computer systems for flight trainers. First, the design of the computer itself was constrained by the availability and accuracy of aerodynamics and system data on the aircraft. Second, once the system was built and testing revealed errors in the aerodynamic data, the computer hardware design had to be changed. Third, the errors and limitations of analog systems led to serious acceptability issues with users. These difficulties motivated the exploration of digital technology. The expected advantages of this technology were (a) that programming would be independent of the computer and input-output system design and (b) changes in aircraft aerodynamic data could be incorporated without hardware changes to the computer system in most cases.

The failure of Whirlwind as a real-time digital computer for application to flight simulation triggered an investigation into the reasons for the failure and led to the research necessary to develop the required technology. This study was initiated in 1949 and continued through 1955. It was conducted by the Moore School of Engineering at the University of Pennsylvania under the sponsorship of the Navy. The results of the early study in 1950 (5) concluded that there did not exist a digital computer system capable of solving the flight equations for one airplane in real time using integration schemes in common use at that time. However, later studies from 1952 to 1954 concluded that the real-time simulation of aircraft using a digital computer was feasible (6). The basis for this conclusion was the development of (a) high-speed random access memory and digital computer logic which increased the speed of computation, (b) new methods of numerical integration which were consistent with the speed of the then current digital computers, and (c) time-efficient methods of function generation for calculating aerodynamic coefficients and stability derivatives.

In 1956 a contract was awarded under the sponsorship of the Navy and the Air Force for the design, development, and construction of a digital computer system in accordance with the logical computer structure and circuits designed and developed by the Moore School. This development effort came to be known as the Universal Digital Operational Flight Trainer (UDOFT) (7). The purpose of this effort was to demonstrate that a digital computer system could be designed to simulate in real time subsonic and supersonic jet aircraft (F9F-2 and F-100A respectively) utilizing the appropriate cockpit configurations and an associated instructor control station. Benefits derived from the use of a digital computer system were improved accuracy, flexibility, and the relative ease of programming. The computational capability of the UDOFT computer system is provided in Table I. Table I also summarizes the essential characteristics of digital computers used in flight trainers keyed to the time of development.

TABLE I. FLIGHT TRAINER COMPUTER SYSTEM CHARACTERISTICS

| AIRCRAFT | DEVICE/ TYPE | TIME FRAME | NUMBER & TYPE OF CPU | ACCESS TIME (SEC) | RAM WORDS | TYPE OF RAM | MASS STORE | PROGRAM LANGUAGE | CPU/ COCKPIT | TYPE CONFIG |
|---|---|---|---|---|---|---|---|---|---|---|
| F9F-2 or F-100A | UDOFT | 1960 | 1 - SPECIAL PURPOSE DIGITAL COMPUTER | 5 μSEC | 8 KW | CORE | NONE | MACHINE LANGUAGE | 1/1 | 1 |
| A-7A | 2F84 OFT | 1964 | 1 - DDP-224 | 5 μSEC | 32 KW | CORE | NONE | ASSEMBLY | 1/1 | 1 |
| TA-4F | 2F90 OFT | 1968 | 2 - SIGMA 5 | 850 NSEC | 8 KW-FLIGHT<br>16 KW-SYSTEM<br>8 KW-SHARED | CORE | NONE | ASSEMBLY | 2/4 | 2 |
| T-2C | 2F101 OFT | 1970 | 4 - PDP 11/45 | 850 NSEC | 48 KW EACH | CORE | 4-1 MB DISC | ASSEMBLY | 4/4 | 3 |
| F-14A | 2F95 OFT | 1970 | 1 - SIGMA 5 | 850 NSEC | 32 KW EACH | CORE | 1-3 MB DISC | ASSEMBLY | 1/1 | 1 |
| A-4M | 2F108 OFT | 1972 | 1 - DATACRAFT 6024/5 | 1 μSEC | 32 KW | CORE | 1-0.5 MB DISC | ASSEMBLY | 1/1 | 1 |
| F/A-18 | 2F132 OFT | 1979 | 4 - SEL 32/77 | 600 NSEC | 128 KW EACH<br>64 KW SHARED | MOS | 2-300 MB DISC | FORTRAN | 4/1 | 4 |

## COMPUTER SYSTEM ARCHITECTURE

The computer design and mathematical developments which led to the initial operation of UDOFT had a significant effect upon the computer community. However, with the invention of the transistor and the rapid acceptance of the digital computer in the commercial world of the late fifties and sixties, the available computational power increased by an order of magnitude and the cost of digital hardware decreased. The effects of these trends can be clearly traced from the UDOFT baseline to current day systems.

Let us consider the area of computer system architecture as it was applied to real-time flight trainers. The early constraints of minimal memory availability and arithmetic processing capability coupled with high cost generally led to a design strategy of performing only the basic aircraft and related systems modeling in the digital computer. As a result many of the input and output operations were performed in the interface unit, such as formatting for data entry, digital to voltage and shaft position conversion and binary to decimal conversion. The technology was generally that of discrete component circuit boards.

An example is the UDOFT system. Its random access memory size was 8192 20-bit words with a magnetic tape utilized for external storage of programs and data. A block diagram of the computer system is shown in figure 1. The central processing unit (CPU) was specially designed to perform the numerical calculations necessary (function generation, integration, coordinate transformations, etc.) for simulation of aircraft. The F9F-2 or F-100A jet fighters were the aircraft types selected to demonstrate feasibility.

The first flight trainer development which utilized a commercially available general purpose digital computer in its computer subsystem was Device 2F84 A7A Weapon System Trainer. This flight trainer employed a single DDP-224 computer. A block diagram of this computer system is shown in figure 2. The design was a direct outgrowth of the research efforts on UDOFT. The one major goal, namely that of using a commercially developed computer was successfully accomplished. Another major research goal, that of separating computer development from trainer hardware development, was also achieved. This achievement permitted the initial aerodynamic and stability data, which are usually inaccurate or incomplete, to be updated through reprogramming.

As computer technology advanced, the computer system designs of flight trainer systems also underwent change. Device 2F90, TA4J Operational Flight Trainer, used a multi-processor system architecture (8). In this system two CPU's shared the computational load for four simulated TA-4J aircrafts. A block diagram of the computer system is shown in figure 3. The computations were allocated to each of the CPU's by function. As a result both CPU's were required for system operation. The advantage of this system was the computing capability possessed by nature of the CPU's operating simultaneously; its disadvantage was that it had undesirable reliability characteristics in that if one CPU failed, the system became inoperative. It also complicated the programming task and made manufacturing and engineering tests more complex.

Experience from this system led to the design concept of distributed processing. The computational load was divided into its lowest common denominator; i.e., one CPU per cockpit. This concept had the advantage of parallel processing to conserve time, ease of manufacturing and checkout, and system reliability. It also permitted the number of trainee stations to be reduced or expanded without a change to the basic system design. The 2F101, T2C Operational Flight Trainer, consisted of four CPU's driving four cockpits (Figure 4). Each individual computer system provided the computational power for calculating the flight simulation (equations of flight), the aircraft system, the instructor station, and performing the operations of the executive system. Note that more and more functions are being assumed by the digital computer.

The development of Device 2F131, A6E Operational Flight Trainer, and 2F132, F18A Operational Flight Trainer, represented a major turning point in the application of digital computer technology to flight trainers. The specifications for this trainer required simulation of a rather complex aircraft, the inclusion of an extensive number of malfunctions, and the augmentation of problem control and scenario generation capability through an interactive CRT keyboard system. A 30-Hz iteration requirement for the critical flight equations was specified. These design requirements led to a computer configuration for the device consisting of four CPU's to support one trainee station. The fivefold increase in memory requirements over previous systems dramatized the impact of the change in functional requirement coupled in some way to the decreases in the cost of digital computers. Computing speed and memory capacity of current day systems led to serious software design and validation problems which currently exist. These software problems have contributed significantly to the lengthening of the development cycle. The advantages of hardware redundancy, manufacturability, life-cycle support costs, and programming checkouts were further enhanced. In addition, the parallel processing within the system minimized the transport delay problem. Figure 5 shows a block diagram of the computer system for Device 2F132.

At the present time, research is being conducted in the area of distributed processor computer system architecture. The thrust is to further extend the distributed processor concept or aircraft into subdivisions each with its own mini- or microprocessors. The increased complexity of aircraft (for example, the F18 of today versus the F9 of the mid-fifties, and the increased computing power of mini-and microcomputers) have made this alternative attractive and logical. As time has passed, more and more of the simulation functions have been assumed by the digital system portions of the trainer simulator. Microprocessor technology has resulted in a shift in the location of the data distribution and conversion system from the computer area to the cockpit. This design minimizes the cockpit to computer cabling requirement.

## ITERATION RATES

The use of the general-purpose digital computer for obtaining numerical solutions of the flight equations in real time raised the signifi-

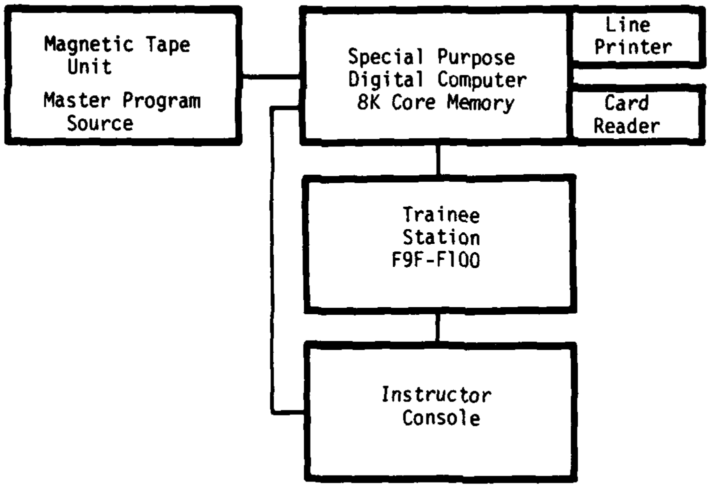



Figure 1. UDOFT Computer System Block Diagram

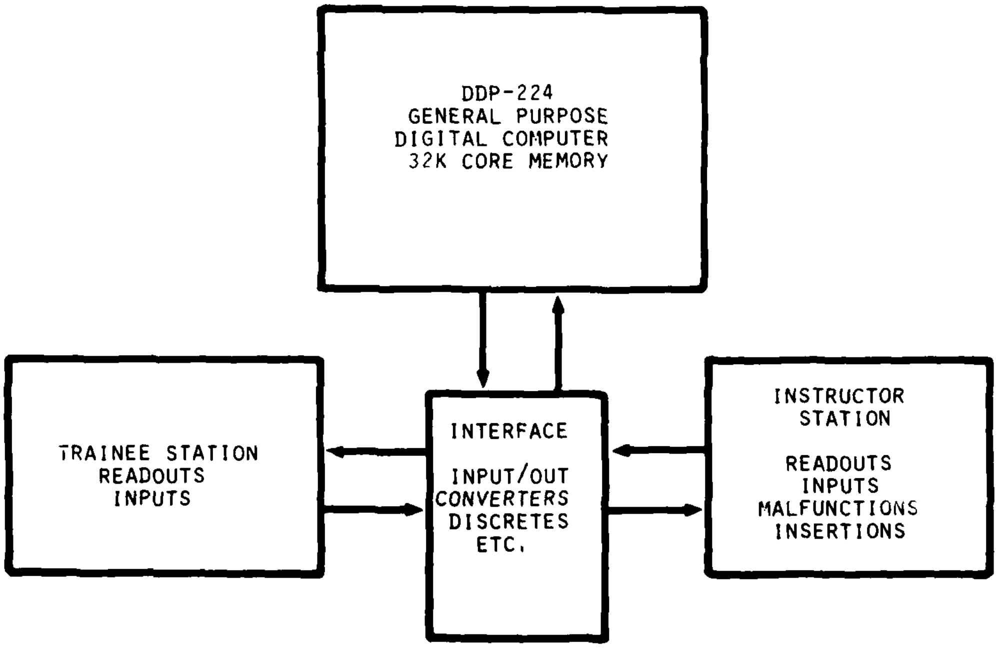



Figure 2. A7A Computer System Block Diagram

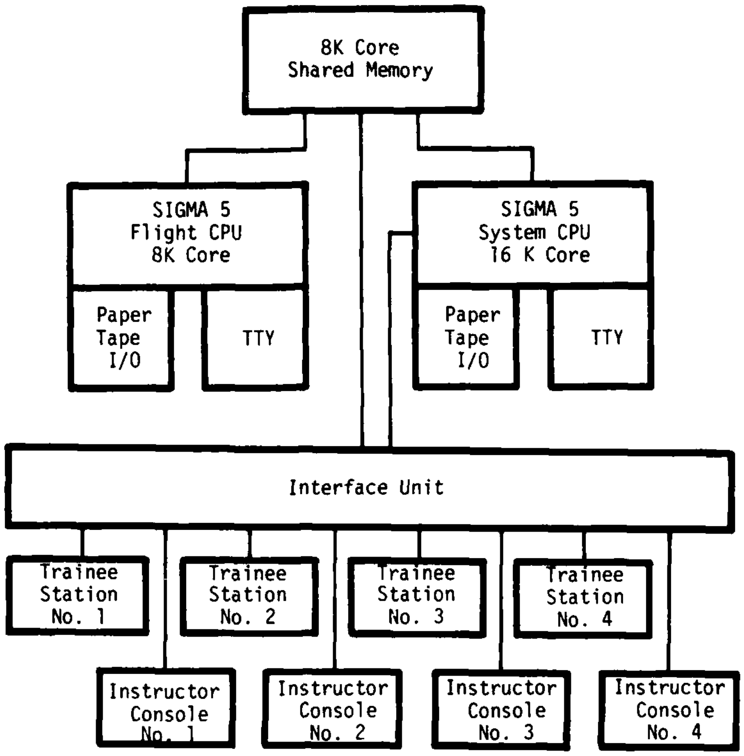



Figure 3. 2F90 Computer System Block Diagram

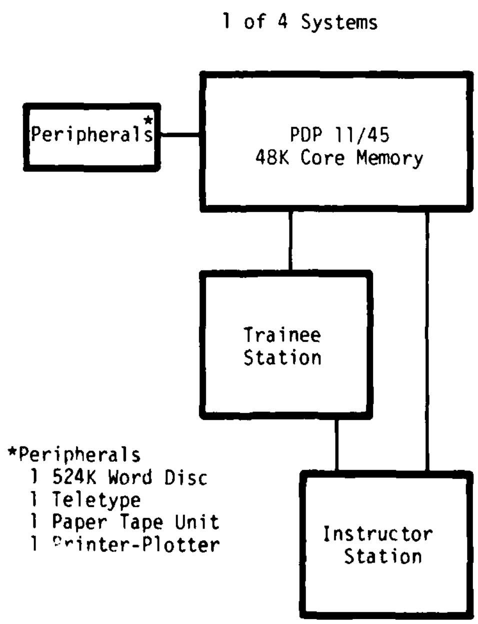
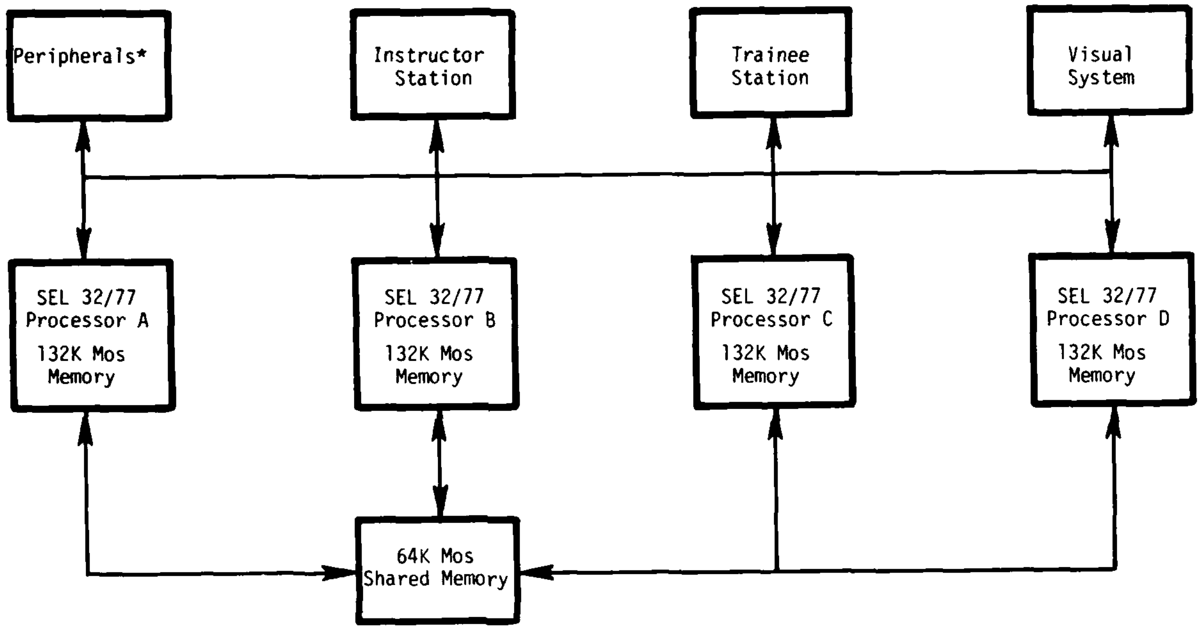



Figure 4. 2F101 Computer System Block Diagram




*Peripherals

1 Printer-Plotter
1 CRT Terminal
1 Magnetic Tape Unit
2 300 MByte Disc

CPU A - Master, Executive, Instructional Features, Data Record
CPU B - EOM, Aerodynamics, Visual Interface
CPU C - Aircraft System, Motion System, Real Time I/O
CPU D - Aircraft System, Aerodynamics, Mission Computer Interface, Flight Hardware Interface

Figure 5. 2F132 Computer System Block Diagram

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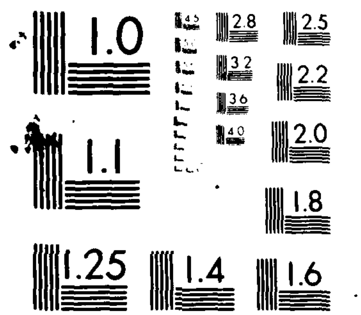


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

cant issue of the iteration rates at which the equations must be solved to ensure stable and accurate computation. The initial program designs used the heuristically established iteration rate of 20 Hz. Since the outputs from the digital computer driving the instruments were discrete values, an output rate fast enough to create the illusion of continuous motion was necessary. Motion picture technology was the basis for initially selecting the 20 Hz iteration rate. Subsequent investigations established that the aircraft's natural frequencies were in the range of 0.75 to 1.0 Hz and varied directly with speed and inversely with altitude. Theoretical studies of digital sampled data systems have determined that it is necessary to take more than two points per cycle of the highest significant frequency component in a signal in order to recover that signal. Hence, at 20 samples/second, the iteration rate was approximately 10 times that required to represent the ideal aircraft motion as determined by Nyquist rate.

However, other factors are involved. Other aircraft systems influenced the selection of the iteration rate. With one exception, the natural frequency of aircraft subsystems did not exceed those of the aircraft itself. The exception was the flight control system. The pilot has the ability to introduce a step input into the system. Early digital systems did not face computational stability problems at the 20 Hz rate because of the filtering inherent in the analog control system design. Initial attempts to convert the control input directly into digital signals proved disastrous. Preliminary analysis indicates that iteration rates in excess of 1000 Hz may be necessary to achieve stable computations (9).

As system complexity increased, the competition for computational time also increased. This led to the establishment of subdivisions of the highest iteration rate to reduce the number of computations. Program design based on iteration rate subdivision has become common. One finds rates of 16, 8 and 4 Hz, for example. As an expedient, the computations allocated to these rates were sometimes shifted to lower rates when running time constraints could not be satisfied. As a result of these trade-off decisions, serious problems in system performance with man in the loop became evident.

The inability to develop reasonable estimates of computer capacity required for a device has resulted in major expansions in computer capacity and serious programming problems during development. These data led the Navy to reassessment of its spare requirements for time and memory. The spare running time reserve requirement was increased from 25% to 50%. Spare memory requirements were increased from 50% to 100%. The specification change was implemented in 1976. The primary reason for increasing this requirement was to ensure the availability of spare capacity to accommodate changes during the life cycle of the device (between 15 and 20 years). It was also intended to provide a cushion during the design phase, thereby avoiding costly computer system expansion late in the development program.

The transport delay problem was well masked for some time because of the time delay inherent in most instruments utilized by the pilot to control the aircraft. The fidelity of simulation issue, which has always been questionable, was believed to be the culprit. With the advent of visual systems attachments for flight trainers, the severity of the transport delay problem was identified (10). The visual system horizon reference acted as a magnifying glass for aircraft attitude information. Pilot performance in the simulator became erratic. Studies were conducted to determine the acceptable transport delay levels (11). As a result of these studies and the requirement to minimize delays caused by dissimilar and assynchronous iteration rates between the 30 Hz television frame rate and the prevalent 16 Hz flight dynamics update rate, a 30 Hz iteration was established by the Navy.

The selection of the 30 Hz basic iteration rate seemed to have solved the problem. But this was not to be so. The current generation of operational aircraft have general-purpose computers that perform a number of aircraft operations and tactical functions. If this on-board computer accepts input at a given rate, then it would be logical to update that information at its design rate. In some cases the rate has been as high as 50 Hz. This is probably much higher than is required to produce stable and accurate solutions of the flight equations.

PROGRAMMING LANGUAGE AND SOFTWARE ENGINEERING

The initial UDOFT effort was based upon the programming strategy developed by the University of Pennsylvania (12). The strategy was basically machine-language oriented. Programming was geared to saving memory space and achieving execution time efficiency. The executive or operating system, such as it was, was tailored to real-time application. The time frame for the effort was in the late fifties. In addition, the real-time needs of the system had essentially dictated the computer architecture and instruction set design.

With the advent of powerful general-purpose digital computers using solid state design in the early sixties, the need for more effective programming tools became clearly evident, and more powerful assemblers and compilers became available. However, for real-time simulation, only assembly language was utilized. In order to achieve system efficiency for real-time operation, specially designed executives were still required, since real-time clocks and other special input/output devices had to be accommodated in operating system software.

As computing speed continued to increase and the cost of computer hardware for a given capability decreased, assemblers continued to be utilized. There was a gradual shift to the use of the general-purpose operating system provided by the CPU manufacturer instead of a special purpose real-time executive. There was a good reason for this trend. The high-speed minicomputers had a real-time process control market.

As computer hardware technology continued to advance, the low cost systems became more prevalent and very cost effective. Those developments essentially triggered a shift of emphasis from a computer hardware based development to a software intensive environment. This shift had a major impact on trainer development. First, it caused an increase in the number of functions which could be performed by a given computing system. Second, it caused a significant increase in the amount of programming required which, in turn, led to a search for more productive methods for developing software. The use of higher order languages (HOL's) in this regard became of interest. However, most HOL's were relatively time and memory inefficient for use in real-time systems. This led to a need for increased computer capacity.

The feasibility of a simulation oriented, real-time HOL was investigated in the early seventies. Initial response was that existing HOL's could not do the job effectively. Studies were conducted by the University of Florida (13) to specify a language applicable to real-time simulation for training and to identify problem areas which needed further work. The Air Force also conducted a study into the applicability of FORTRAN for real-time simulation (14).

In general, these studies showed that application of HOL's for real-time simulation programming would be feasible, but that additional language features and run-time efficiencies would be required to make the application reasonably effective. With the recognition of the trends in software development stated above, an Engineering Dept. Directive was issued by the Naval Training Equipment Center in 1973. This Directive established the need for HOL's and identified the use of FORTRAN as a short range goal. The first specification to require the use of FORTRAN was Specification 2222-1139A, Specification for Air Combat Manuevering Simulator, Device 2E6, dated 16 August 1976.

Initially, the industry reaction to this requirement was negative. The desire to circumvent the requirement led to many criticisms of FORTRAN, but soon this resistance waned and the benefits of FORTRAN began to be extolled. Two papers (15, 16) presented at the Naval Training Equipment Center's Industry Conferences indicated the relative effectiveness of FORTRAN. Deficiencies identified in previous studies of the applicability of the FORTRAN compiler were restated. The relative compiler efficiency between manufactures was also identified. The requirement for the use of FORTRAN is now generally accepted. The timing for this acceptance was perhaps fortuitous. The increasing demand for instructional capability coupled with increased system complexity has caused a software engineering explosion.

It would be unthinkable to discuss computers and real-time programming without addressing the critical software problem which faces industry. The software explosion is dramatically portrayed by the data presented in figure 6. Even with the low cost computer systems that are available in the market place, numerous projects have substantially exceeded the bid stage CPU estimates of both run time and memory capacity. The sheer size of the programming effort and the lack of adequate control of software development has destroyed the credibility of software designers. Program and engineering managers are eagerly seeking solutions to this problem, a problem which has finally received their attention. The government has taken the initiative by requiring a more vigorous and disciplined approach to software development. The Air Force has adopted Air Force Regulation 800-14. The Navy has adopted MILSTD 1644. Efforts are underway to standardize these documents.

Today, the trend is toward the adoption of ADA, the DOD HOL, when it becomes available. In fact, the Computer Systems Laboratory of the Naval Training Equipment Center has participated in the Phase III evaluation of ADA for a trainer real-time simulation application.

In addition to a disciplined approach to the development process, there is a pressing need for more information about the characteristics of the program. The data shown in Table II is only one way to show the structure of the program. Another, and perhaps more meaningful from an analysis viewpoint, would be a breakdown by numerical function, such as integration, function generation, coordinate transformation, searches, logical computation, and others. This breakdown is subroutine oriented. Such data would reveal more about what the program is doing. A further extension of this breakdown would be a count of the number of times each instruction is executed in a program cycle. Why this need? A search of the literature shows little documentation along these lines. The sketchy nature of the data shown in Figure 2 and the failure of a literature search to show any data on real-time program structure support this position. Efforts are being initiated at NAVTRAEQUIPCEN in the Computer Systems Laboratory to collect such data as an adjunct to computer research tasks. We encourage industry to do the same and to share these results with the training device community. This type of shared data should materially contribute to the solution of this critical problem.

FUTURE TRENDS

The advance of large-scale integrated micro electronics is causing a revolution in computer industry. Researchers predict that it will be possible to fabricate $10^6$ gates on a single chip. Indeed some very large scale integration (VLSI) technology in the form of micro computers, micro processors, and related system device elements exists at the present time. Computer system approaches using microprocessors and microcomputers in functionally distributed architectures are not far over the horizon.

Functionally-modular system architectures will drive the future real-time trainer software developments to modular software. These software modules will be application-unique and will be dedicated to individual microcomputers that are organized and controlled as a distributed microcomputer system. Such a system will not be the same as the conventional master/slave system approach. As software modules are developed for various classes of trainers, the source code of these modules (e.g., in ADA, Pascal, FORTRAN, assembly code) can be standardized and transported between trainers of the same class. This will be a significant step toward reducing the life cycle costs of trainers.

In the past, flight trainers have generally been designed without regard to the instructional environment of which they will become a part. Simply stated, a flight trainer is developed as a hardware item. Curricula development usually was undertaken by the using activity. The task of operating the device and developing training scenarios was within the capability of the assigned instructor and operator personnel. With the complex aircraft and the instructional programs required to support today's training needs, it has become obvious that substantial amounts of assistance must be provided

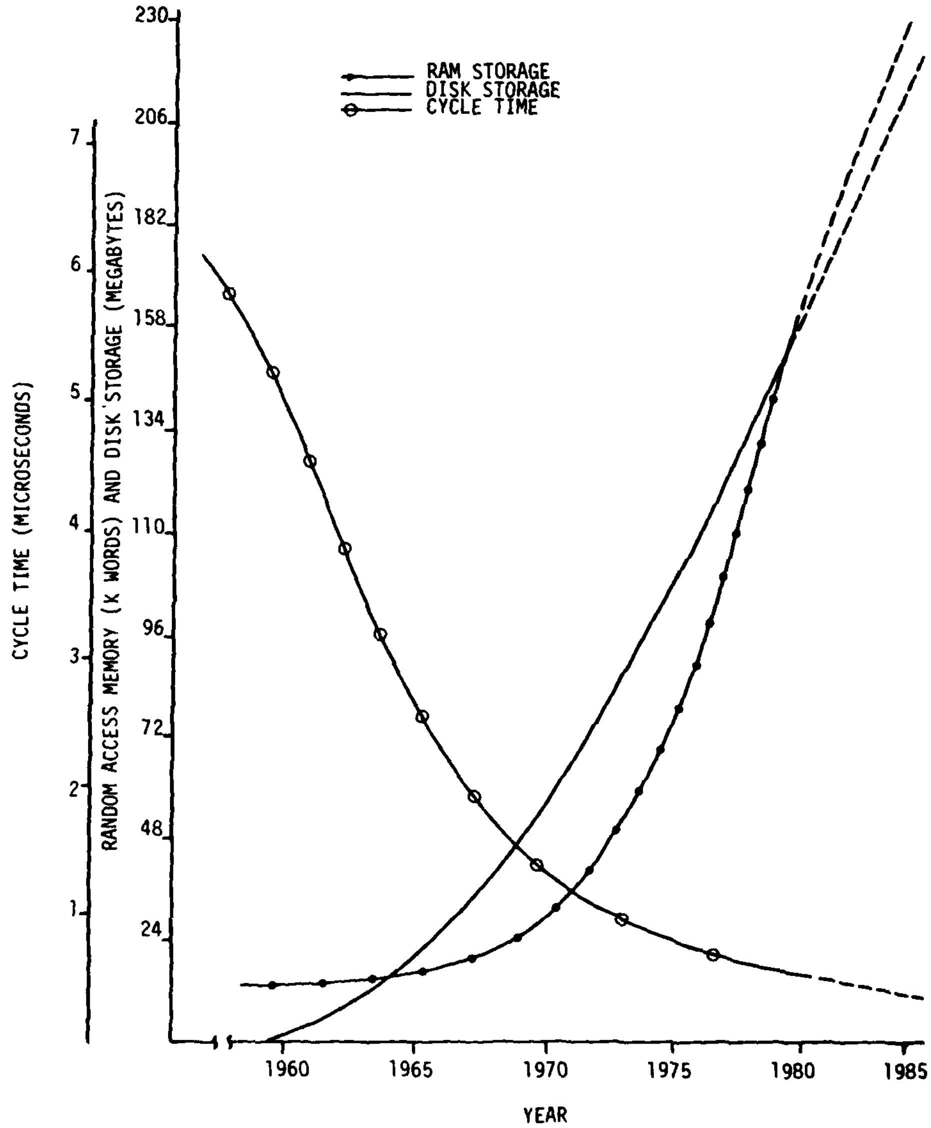


Figure 6. Flight Trainer Computing System Trends

TABLE II. PERCENT MEMORY DISTRIBUTION/CPU BY PROGRAM MODULE

| FUNCTION \ CPU/COCKPIT | UDOFT | 2F84 | 2F90 | 2F101 | 2F95 | 2F108 | 2F132 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1/1 | 1/1 | 2/4* | 4/4 | 1/1 | 1/1 | 4/1 | | | |
| | | | | | | | 1 | 2 | 3 | 4 |
| Flight Simulation | 45.6 | 28.3 | 23.4 | 9.0 | 40.2 | 11.8 | 9.2 | 57.2 | - | 16.2 |
| Aircraft Instruments | 33.4 | 15.8 | 3.2 | - | - | 9.7 | - | - | - | - |
| Aircraft Systems | 5.6 | 20.3 | 15.3 | 20.5 | 16.4 | 16.2 | - | - | 38.9 | 29.9 |
| Com/Nav | - | 15.4 | 6.4 | - | 20.3 | 19.1 | - | - | - | 12.9 |
| Flight Hardware Int. | - | - | - | - | - | - | - | - | - | 2.6 |
| Mission Computer Int. | - | - | - | - | - | - | - | - | - | 2.9 |
| Carrier Dynamics | - | - | - | - | - | - | - | - | 13.2 | - |
| Visual System Int. | - | - | - | - | - | - | - | 8.2 | - | - |
| Instructor Console | 10.4 | 8.4 | 15.8 | 45.8 | 13.9 | 13.2 | 47.3 | - | - | - |
| Math Lib | - | - | 10.7 | - | - | - | - | - | - | - |
| Executive | - | 5.5 | 3.9 | 8.1 | 5.8 | 5.3 | 4.5 | 5.6 | 5.9 | 4.5 |
| Spare | 5.0 | 6.3 | 21.3 | 16.6 | 3.4 | 24.7 | 39.0 | 29.0 | 42.0 | 31.0 |
| Random Access Memory | 8K | 32K | 24K | 48K | 32K | 32K | 128K | 128K | 128K | 128K |
| | | | | | | | 64K SHARED | | | |
| Mass Memory | NONE | NONE | NONE | 1MB | 3MB | 5MB | 2 - 300MB | | | |

* Normalized to a 1 CPU Configuration

to instructors and operators.

A 6.4 Engineering Development program entitled "Aviation Weapons System Simulation" was initiated in 1978. The objective of this program was to conduct research so that instructor and operator workload could be reduced while improving the effectiveness of training at the same time. The project called for the development of a training system that was individualized and adaptive with voice synthesis and performance measurement subsystems. Such an instruction system strap-on package is about to be delivered for integration with Device 2F95A F14 OFT. This modular package itself contains a computer system made up of two digital computers, one-S/130 and one-S/250 with a 96 megabyte disc for mass data storage. The major features of this system include management and recordkeeping, data on student performance, briefings on problem setup and scenario generation for the instructor, performance measurement, problem diagnosis with feedback for students, and use of voice technology to assist the instructor/operator (17).

Although there is increased sophistication and complexity in evolving aircraft weapon systems, the major trend for future flight simulators will be the inclusion of a complete instructional system with a training strategy at the outset of the development process. The F14 OFT strap-on package is intended to demonstrate the application of instructional technology to complex trainers. Based on the evaluation of this system we can anticipate substantial emphasis in the instructional system aspect of major trainer developments in the future.

The software problem has been highlighted. It is easy to propose procedurally oriented solutions. However, it is somewhat more difficult to change organizational and management structures to effect the desired results. To bring order to the software development process, it will be broken down into its essential elements and geared to high-volume throughput. These elements are design, manufacturing, and test.

The design phase will rely on the increased use of standards, and a formal design release and control system. An independent software development or manufacturing facility (for coding, compiling, editing, testing and documenting, etc.), which has the necessary software production and configuration control machine tools, will be established. Such facilities would improve the effectiveness and increase the throughput of the software development process. And finally, a fully independent test and quality assurance program will be established. Software/hardware integration testing will be included in this phase. The establishment of independent design, manufacturing and testing functions will not remove the programmer from the software development process. It will create a number of specifications within the field. It will also provide visibility of software development for control and accountability purposes. Software systems will become another component of system development, not an end into itself.

## CONCLUSION

The evolution of real-time digital simulation for flight trainers has been traced from the initial research studies conducted by the University of Pennsylvania which were initiated in 1949. From that baseline computer system design, the computer and programming technology related to this field have gone through a number of evolutions. These evolutions have been geared to the technological advances in the computer field. With respect to computer architecture, the trend was one of going from expensive CPU's with speed and memory capability that were barely adequate for the task, to the present system architecture of inexpensive and powerful distributed processors based on a functional allocation to the subsystems involved in the flight trainers. In the future, highly efficient distributed processor systems can reasonably be expected. Current iteration requirements, 30 Hz, are geared to synchronous-type operation with television-type systems. Iteration rates will be influenced by aircraft on-board computers whose iteration rates may exceed the 30 Hz standard which has been established. Progress will be made in the use of FORTRAN as more efficient compilers are developed by computer manufacturers for real-time simulation. The magnitude of the software development effort requires a highly disciplined approach to its design, manufacture, quality assurance, and test so that the software subsystem can take its place as a mature engineering discipline. ADA will be introduced as soon as its development is complete. The next generation of flight training systems will incorporate intensive use of instructional features to improve training effectiveness while minimizing the use of energy and human resources.

## ACKNOWLEDGEMENTS

The authors gratefully recognize the work of Mr. Gerald A. Wyndle of the Computer Systems Laboratory, NTEC, who significantly aided in the preparation of this paper by gathering data and putting it in an appropriate form for publication.

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MR. G. VINCENT AMICO has been Director of Research at the Naval Training Equipment Center since 1979. He graduated from New York University with a Bachelor of Aeronautical Engineering in 1941. He was awarded a Masters in Business Administration from Hofstra College in 1954 and a Master of Science in Engineering from Florida Technological University in 1973. Mr. Amico worked on the design of naval aircraft as a stress analyst and project stress engineer from 1941 to 1945. He entered the Armed Forces in 1945 and was assigned to the Static Test Unit of the Structures Laboratory at Wright Field as a structure research engineer. Upon leaving the service in 1947, Mr. Amico joined Republic Aviation Corporation with responsibility for preliminary design of missile and advanced aircraft systems. He joined the Center in the fall of 1948 as a project engineer in the Flight Trainers Branch. Since then he has progressed through the engineering organization, holding positions as Head of the VA-VP OFT Branch; Head of the Aviation Trainers Division; Deputy Director and Chief Engineer of the Special Projects Office and Director of the Sea Warfare Trainers Department. In 1969 Mr. Amico was appointed Director of Engineering. He held that position until he was reassigned as Director of Research in August of 1979. During this time, he was responsible for the development and production of a wide variety of training devices in all warfare areas. Mr. Amico is a member of Tau Beta Pi and Alpha Pi Mu Honorary Engineering Fraternities, Research Society of America, Sigma Xi, the American Institute for Aeronautics and Astronautics. Mr. Amico has been associated with the research and development program relating to real time simulation using digital computers since 1952. He has also played a major role in the application of digital systems to all training devices.

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Lindahl received a B.S. degree in electrical engineering in 1952 from Case Institute of Technology, Cleveland, Ohio and the M.S.E. and Ph.D. degrees in electrical engineering from the University of Michigan, Ann Arbor, Michigan in 1957 and 1968 respectively.

# DATA ACQUISITION AND ANALYSIS SYSTEM AS A TRAINING DEVICE FOR SIMULATED CONVENTIONAL WEAPON DELIVERY

by

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## 1. INTRODUCTION

The tasks to be performed by the pilot during conventional weapon delivery in high speed fighter aircraft depend on the systems available aboard the aircraft, and on the type of weapon used.
Presently the main part of the air-to-ground training method in the Netherlands consists of the delivery of training bombs at training ranges.
The disadvantages of this method are:
- the site of weapon delivery (and in many cases also the direction from which the attack is initiated) is often the same (learning effect!)
- the performance of the pilot is expressed in one quantity only: the score. The release conditions are not measured
- the high consumption of weapons (expensive!).

In order to avoid these disadvantages, a simple system, called: "Delivery and Impact Analysis System" (DIAS) has been developed and tested by the National Aerospace Laboratory NLR, under contract for the Royal Netherlands Air Force (RNLAF).
This system, based on a photogrammetric method, yields release conditions, the nominal weapon impact position and the weapon time of flight. Simulated attacks on a great variety of realistic targets can easily be evaluated and validated as there is no need to drop training weapons. Furthermore no ground-based instrumentation in the target area is needed. The system consisting of an airborne data acquisition system installed in the aircraft and a ground-based processing and analysis system at the airbase allows a debriefing of the pilot within half an hour after completion of the mission.
This paper gives a description of the system. Attention is paid to the system requirements, the system evaluation and the implementation in an operational NF-5 squadron of the RNLAF.

## 2. SYSTEM REQUIREMENTS

The RNLAF using, among others, NF-5 aircraft to carry out low level attacks wished to have a system realized for that type of aircraft which should meet the following requirements:

1. Accurate assessment of pilot performance concerning simulated weapon delivery in an (semi) operational environment by yielding:
   - weapon release conditions and
   - weapon impact positions for each attack run
   - statistical overviews of the mission results in relation to pilot, weapon, target, dive angle etc.
2. Training of pilots concerning weapon delivery by a fast feed-back of the mission results.
3. A simple system characterized by:
   - a minimum of equipment
   - a minimum of personel
   - low costs
   - no influence on pilot procedures during weapon delivery
   - easy handling of the airborne system on the ground
   - user's friendly processing and analysis system.
4. No ground equipment in the target area.
5. No aircraft modifications.
6. No influence on the operational status and handling qualities of the aircraft.

Although the system has no war task and therefore, no back-up system is needed, the RNLAF expressed the following requirements concerning the "mean time between failures" (MTBF):
- airborne system: 100 flying hours
- ground-based system: 1000 working hours.

Based on the number of required "DIAS" sorties per aircraft and the related working hours of the ground-based system one failure every half a year may occur.

## 3. SYSTEM DESCRIPTION

### 3.1 Introduction

DIAS consists of two parts, namely:
- an airborne data acquisition system attached to the aircraft and
- a ground-based data processing and analysis system at the airbase.

The airborne system contains a photo camera by which at the moment of weapon delivery two photographs of a once measured target area are taken. The information available from both photographs is processed and analyzed with the aid of the ground-based system and yields the results of the attack carried out.
The ground-based system comprises, among others, a minicomputer, a display terminal and a photo reader.
A "DIAS squadron" has at its disposal several aircraft equipped with an airborne system and one ground-based system.

### 3.2 Airborne data acquisition system

The airborne system of DIAS contains the following components:
- a photo camera (24 x 36 mm), ROBOT motor recorder 36 C, 24 VDC with an exposure time of 1/500 s. The camera is equipped with an object-glass "Schneider Xenon" f/1.9 -50 mm and a central type shutter
- a release magneto (solenoid)
- an automatic diaphragm control unit of which the electronics were modified and integrated with
- an electronic unit, designed to control the camera
- a housing provided with a front glass and a retractable screen controlled by an electric motor (TRW Globe Motors, type 5 A 548-8).

The camera is attached to the aircraft in an upright position with the optical axis pointing forward, 11 degrees nose down with respect to the aircraft's longitudinal axis. No relevant part of the camera field of view is obscured by any store attached to the centerline pylon.

At the moment of weapon delivery the camera is activated by pressing the bomb button (pilot's action) while for the second photograph the camera is activated automatically 340 ms later by the electronic unit which also controls the camera diaphragm and film transportation.
The housing of the airborne system has been attached to the aircraft on the spot of the nose part of the centerline pylon which has been removed. The difference between the original and "DIAS" centerline pylon of the NF-5A concerning the external shape is shown in figure 1.

The housing consists of two parts of which one is attached to the centerline pylon permanently and contains the electronic unit. The second part, the "DIAS nose", is attached to the first part by two "quick release latches" (easy removable) and contains the photo camera (Fig.2).

Fig. 1 The original- and DIAS centerline pylon of the NF-5A aircraft

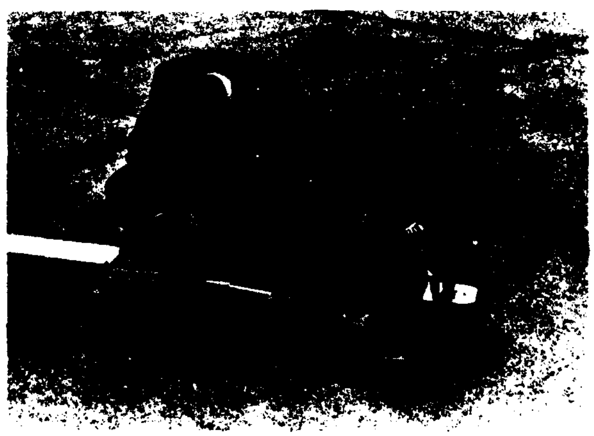

Fig. 2 The DIAS nose removed from the modified centerline pylon

After completion of the flight the "DIAS nose", is brought to the squadron building where the film is removed (easy accessible) and developed.
If no DIAS mission is carried out the real "DIAS nose" is replaced by a "dummy nose" with an identical external shape (Fig.3).

The housing of the airborne system is designed such that all centerline stores can be carried as before (Fig.4).

Fig. 3 The real and dummy DIAS nose

Fig. 4 The rocket bomb dispenser attached to the DIAS centerline pylon

The retractable screen which protects the front glass of the housing against dust and salt (low level missions) will be opened during the weapon delivery phase through the activation (pilot's action) of either the "bomb arming switch" (bombing) or the "armament position selector switch centerline" (rocketry). Pilot's actions during a "DIAS mission" do not differ from those to be carried out normally during an attack mission. In addition to the modification of the centerline pylon construction a minor modification concerning electrical wiring inside the pylon was needed (power supply, signals to camera). Aircraft modifications are not involved.

3.3 Ground-based data processing and analysis system

The ground-based data processing and analysis system that is situated at the airbase consists of the following components:

- PCD photo reader ZAE 71.
- DEC general purpose computer PDP 11/34 (16 bits, 64 k words MOS memory).
- DEC LA-36 printer .
- Lear Siegler ADM-42 visual display unit.
- 2 RL01 disk units (5 M bytes).

The selection of the components of the ground-based system has been based on, among others, the following requirements:

- Floating point hardware (accuracy and speed of calculation program).
- High order language with real-time facilities (Basic 2+) (easy accessible and short time for development).
- Interactive programming facilities (editing activities).
- System reliability (mean time between failures is 1000 hours).
- Standardization in the RNLAF.
- Costs.

With the aid of the photo-reader the developed film negatives are projected on a high resolution screen. The once measured reference points (terrain features) in the target area, visible on the projection, are digitized and sent to the computer. On the basis of this information together with briefing data (meteorological conditions, aircraft weight and configuration etc. given by the pilot) and data stored on the magnetic disk (specifications of camera, target, etc.) the analysis of the attack is carried out.

The results of the attack run are displayed on a printer output (Tab.1).

All run results are stored on disk to provide a statistical overview of the results in relation to pilot, weapon, target etc. (Tab.2).

TABLE 1

DIAS RUN RESULTS

SORTIE: RUN: DATE:<br>
PILOT : FLIGHT POSITION:<br>
AIRCRAFT: K- FLAPS: SCL: FUEL: (lbs)<br>
CAMERA: TARGET:<br>
WEAPON: DELAY TIME: (s) SIGHT SETTING (mils)<br>
WIND: (deg)/ (kts) CODE: QNH: (mb) OAT: (°C)

| DELIVERY PARAMETERS: | PLANNED | ACTUAL | ERROR |
|---|---|---|---|
| TAS (kts) | | | |
| IAS (kts) | ——— | | ——— |
| DIVE ANGLE (deg) | | | |
| HEIGHT (ft) | | | (%) |
| SLANT RANGE (ft) | ——— | | ——— |
| NORMAL LOAD (g) | | | |

PITCH ANGLE (deg): BANK ANGLE (deg): ANGLE OF ATTACK (mils):<br>
HEADING (deg): TRACK (deg):<br>
PIPPER POSITION: LONGITUDINAL (mils): LATERAL (mils):<br>
ON PHOTOGRAPH LONGITUDINAL (%): LATERAL (%):

SIMULATED IMPACT POSITION: RANGE ERROR (ft) :<br>
DEFLECTION ERROR (ft) :<br>
WEAPON TIME OF FLIGHT (s):<br>
TARGET REF. POINTS NOT ACCEPTED: PHOTO 1: PHOTO 2:<br>
AIRCRAFT REF; POINTS NOT ACCEPTED: PHOTO 1: PHOTO 2:<br>
(CONSIDERING HEADING, TRACK, BANK ANGLE AND CROSS WIND A SIDE-SLIP WAS PROBABLY INTRODUCED)<br>
(ACTUAL DELIVERY PARAMETERS OUT OF BOMB TABLE RANGE)

TABLE 2

STATISTICS OF DIAS RUN RESULTS

| DATE OF PRINTOUT: | | OPERATOR: | VERSION: |
|---|---|---|---|
| SELECTED PARAMETER | VALUE | LOWER BOUND | UPPER BOUND |
| DATE | | | |
| SORTIE NUMBER | | | |
| PILOT CODE | | | |
| FLIGHT POSITION | | | |
| AIRCRAFT CODE | | | |
| CAMERA CODE | | | |
| TARGET CODE | | | |
| WEAPON CODE | | | |
| PLANNED TAS (kts) | | | |
| PLANNED DIVE ANGLE (deg) | | | |
| PLANNED HEIGHT (ft) | | | |
| LIFE DELIVERY (NO/YES) | | | |

| DELIVERY PARAMETERS (NUMBER OF RUNS = ) | MEAN | ST.DEVIATION |
|---|---|---|
| TAS ERROR (kts) | | |
| DIVE ANGLE ERROR (deg) | | |
| BANK ANGLE (deg) | | |
| NORMAL LOAD (g) | | |
| HEIGHT ERROR (%) | | |
| SIMULATED IMPACT (NUMBER OF RUNS= ) | | |
| RANGE ERROR (ft) | | |
| DELFLECTION ERROR (ft) | | |
| ACTUAL IMPACT (NUMBER OF RUNS= ) | | |
| RANGE ERROR (ft) | | |
| DEFLECTION ERROR (ft) | | |
| DUD (NUMBER OF RUNS= ) | | |
| DUD - RATE = % | | |

## 4. SYSTEM EVALUATION

### 4.1 General

After having carried out an investigation about the feasibility of the photogrammetric method to be applied for DIAS (1), the analysis technique was tested. For the system performance tests, life deliveries on a weapon range were executed (2).
Use was made of an instrumented NF-5A test aircraft (3) equipped with a DIAS airborne system (prototype).
The processing of data (photographs) and the data analysis were carried out with the aid of photo-reader and computer facilities of the NLR.

In order to establish the airworthiness of the airborne system, tests on the ground as well as during flight were carried out.

### 4.2 System performance

#### 4.2.1 General

Before DIAS was realized an investigation was carried out to establish the feasibility of such a system. During this study the analysis technique, based on a photogrammetric method was developed. Attention is paid to the analysis method applied in DIAS and information is given about the accuracy of the system. Finally the performance flight tests carried out, to verify the analysis technique are described.

#### 4.2.2 Calculation technique

As already mentioned before mission planning data, available through the pilot, constant system data, stored in the data base of the ground-based system and the information available from two photographs, taken of the target area at the moment of simulated weapon delivery are needed to determine the attack performance.
Table 3 gives an overview of these data.
In the following the analysis method is described in general terms.

The photogrammetric method.

The photogrammetric method, used to determine the position and attitude of a camera with the aid of a photograph, taken of a defined object, is based on the fact that there is only one position from which this object can be seen the way it is displayed on the photograph.
Expressed in mathematical terms:
the camera has to be translated as well as rotated such that the image vectors on the photograph, transformed to the object co-ordinate system, cover completely the object vectors in length and direction.
More background information about the mathematical procedures is given in (4),(5) and (6).

Camera attitude with respect to the aircraft.

The bottom of the forward part of the aircraft

TABLE 3

Data needed for the analysis of a DIAS mission

| subject | mission planning data | data base | mission data |
|---|---|---|---|
| aircraft | - tail number<br>- configuration<br>- fuel remaining over target | - position of reference points and camera<br>- configuration data<br>- gun sight position | |
| target | - target number | - position of reference points including target<br>- target altitude above mean sea level | |
| camera | - camera number | - focus<br>- measures of negative<br>- time period between photos | - 2 photos |
| weapon | - weapon type<br>- fuse arming delay time setting | - ballistic table<br>- maximum fuse arming delay time setting<br>- positive tolerance fuse arming delay time setting | |
| meteorological* conditions in target area | - wind<br>- temperature<br>- pressure (QNH) | | |
| planned delivery data | - dive angle**<br>- airspeed**<br>- release altitude**<br>- sight depression of gun sight | | |

* Normally forecast data are available.
In case of life deliveries on a weapon range actual data are taken.
In case the pilot experiences other wind conditions than forecasted, and he adjusts his planned delivery parameters, the changed wind conditions will be taken for the analysis.

** These data are not needed for the analysis but are used to indicate pilot's errors.

fuselage has been provided with 4 (aircraft) reference points of which the positions together with the camera position have been measured once in relation to the aircraft co-ordinate system. These reference points, visible on the photograph, are used to calibrate the camera attitude for each attack run with the photogrammetric method.

Position and attitude of the aircraft with respect to the target.

Every DIAS target is selected by the requirement of having terrain features which can serve as target reference points. The position of each point is measured once (infrared theodolite) in relation to the target. With these reference points, visible on the photograph, the position and attitude of the camera and thus of the aircraft can be determined. Having analyzed the photograph, taken at the moment of weapon delivery, the following release conditions are already known:

- release altitude
- heading of aircraft.

Together with the second photograph, taken 340 ms after weapon delivery, the following parameters are determined:
- ground speed
- ground track.

Angel of attack, dive angle and true airspeed.

Because of the fact that the dive angle is one of the most critical delivery parameters much attention is paid to calculate this variable as accurate as possible.
During the performance flight tests it appeared that the calculation of the dive angle by using both known positions, was too inaccurate because very often a curved flight path was flown.
For that reason the dive angle is calculated as a function of the angle of attack, true airspeed

(function of ground speed and dive angle), meteorological and aircraft data and taking into account pitch rate effects.
The dive angle calculation is executed, using an iterative process because both angle of attack and dive angle are unknown.
Note: If the wind information is incorrect the true airspedd will also be incorrect. But, as the pilot plans (and executes) the attack with the wind information available, the results are also based on this information.

The normal load factor.

The normal load factor is derived from the true airspeed and angle of attack taking into account pitch rate effects.

Side-slip indication.

In case the aircraft ground track and heading are not identical, the difference may be caused by either drift or slip or by both.
If the difference does not match with the cross wind component and aircraft speed it is concluded that the pilot initiated a side-slip condition. This is indicated in the run results.

Pipper position.

The pipper position in the ground-based reference frame, at the moment of weapon delivery is calculated by using the position of the gun sight with respect to the aircraft reference frame, the aircraft position in relation to the target and taking into account the angle of attack and the sight depression set by the pilot.

Weapon impact position and weapon time of flight.

For the calculation of the (nominal) impact position and time of flight, use is made of ballistic weapon tables, also used by the pilots to plan the delivery.
In case the actual value of a delivery parameter is not available in the table, an interpolation is performed, using a second degree polynomial.

4.2.3 Accuracy

In this section the most important error sources of the system are described. Furthermore an experiment carried out, to determine the errors and their influence on the results are discussed. Finally the overall accuracy will be given.

The most important error sources are:
- measurement of target- and aircraft reference points
- photo-camera
- read-out of photographs
- delay time of weapon release.

Because the system is used in combination with a flying aircraft some system errors are caused by motion only. For that reason distinction is made between "dynamic" and "static" errors.

"DYNAMIC" ERRORS

Shutter time of camera.

The nominal shutter time of the cameras in use is 2 ms which is tested for each camera. This value appears to be correct.
During the exposure of the film the aircraft covers a certain distance in longitudinal direction.
Furthermore the left hand side of the photograph is exposed 1 ms earlier than the right-hand side causing a position shift of reference points on the left-hand side with respect to the points on the right-hand side.
Taking into account an aircraft speed of 500 kt and a slant range of 2000 ft to the target, this shutter time causes a position error of about 3 ft and an attitude error of about 0.02°.

Elapsed time between both photographs.

The electronics which control the time period between both photographs is adjusted to 340 ms.
Tests on the ground as well as in flight showed that the maximum deviation is 1 ms.
Based on an aircraft speed of 500 kt and a timing error of 1 ms a position error of about 1 ft is caused.

Delay time of weapon release.

With flight tests during which actual deliveries were carried out the delay times between "pickle" moment (pilot's action) on the one hand and the real- and "DIAS" release moment (first photograph) on the other hand were measured. The "DIAS" release occurred 33 ms after "pickle" while the actual release took place 25 to 40 ms after "pickle".
Taking into account both the camera- and actual weapon release time delay a difference of 10 ms exists.
Based on that difference and an aircraft speed of 500 kt an impact error of about 8 ft is caused.

"STATIC" ERRORS

Measurement of target- and aircraft reference points.

The positions of the target reference points (geographical features) with respect to the target are measured with the aid of an infrared theodolite.
The accuracy of the measurements is within 10 cm for the relevant distances.

The positions of the aircraft reference points with respect to the photo-camera are measured with the aid of a theodolite. The measurements are carried out with the aircraft levelled (also used for calibration of the gun sight). The accuracy of the measurements is within 1 mm.

Camera focus.

The focal distance (50 mm nominal) of each camera in use is calibrated with an accuracy of o.1 %.

Lens distortion.

To avoid the influence of lens distortion (edges of the lenses) reference points visible on the edge of the photograph (within 10 % of the width) are not used for the analysis.

Read-out of photographs.

The photographs (negative) is enlarged 14 times on the photo-reader screen which means that the projection measures are about 34 x 50 cm.
Read-out tests showed that well defined reference points, visible on the photograph can be read out with an accuracy of 0.2 mm.
The linearity of the photo-reader which has been

tested, is excellently.

Experiment.

In order to establish the total "static" error an experiment was carried out during which with a calibrated camera (fixed position) photographs were taken of an area with 8 reference points. The greatest distance between the camera and the reference points was about 2000 ft. With the aid of the DIAS calculation process the camera position and attitude were determined. This experiment showed a maximum position error of 4.5 ft (standard deviation 1.5 ft) and maximum attitude errors of less than 0.1° (standard deviation 0.03°).

OVERALL ACCURACY

Taking into account the experimental "static" errors as well as the "dynamic" errors (except for "delay time of weapon release") it is concluded that the overall accuracy of the DIAS position and attitude determination process is given by 8 ft and 0.1° (95 % confidence level) respectively.
Based on the position error and the time period of 340 ms between both photographs the maximum airspeed error (95 % probability) is 10 kt.

Making use of the ballistic tables available and taking into account:
- the position-, attitude- and airspeed errors mentioned before
- a less accurate calculation of the angle of attack and dive angle (accuracy is 0.15°) and furthermore the variation of:
- weapon characteristics (weight, drag)
- aircraft characteristics (e.g. lift curve slope)
- meteorological data
- delay time between "DIAS" and actual release moment

The following impact errors* (circular error probable; CEP) were expected during the performance flight tests to be carried out:
- bombing CEP = 50 ft
- gunnery CEP = 55 ft
- rocketry CEP = 60 ft.

4.2.4 Performance flight tests

In order to evaluate the DIAS performance, flight tests were carried out with an instrumented NF-5A test aircraft of the RNLAF (2).
During the program 15 missions, consisting of in total 53 attack runs were carried out on a weapon range. Deleveries were made with 20 MK-106's, 28 BDU-33B's and 5 MK-82 R's.
A number of 8 BDU-33B's were delivered under so-called "bunting relase" conditions (large deviations from "steady state" conditions, especially side-slip).

In the following, information needed for a good understanding of the flight tests results obtained, is given:
1. The target area was provided wigh 9 reference points equally distributed over the area. All points were (always visible) taken into account for the analysis.
2. The actual impact positions were measured accurately.
3. Four photographs within 1 s were taken, to determine the best time interval for future DIAS photographs.
4. The release conditions varied as follows:
   - dive angle : 0 -15 deg
   - slant range : 1200 - 2300 ft
   - release height : 170 - 630 ft
   - airspeed : 415 - 500 kt
   - normal load : 0.9 - 1.4 g.
5. Use was made of actual meteorological data.

From the performance flight tests the following conclusions can be summarized:
1. The circular error probable (CEP) and standard deviation(S) of the differences between the actual and predicted (DIAS) impact positions, were:
   a. BDU-33B
      20 deliveries "steady state" release conditions:
      CEP = 35 ft S = 32 ft
      8 deliveries "bunting" release conditions:
      CEP = 81 ft S = 47 ft
   b. MK-106
      20 deliveries "steady state" release conditions:
      CEP = 42 ft S = 21 ft
   c. MK-82R
      5 deliveries "steady state" release conditions:
      CEP = 43 ft S = 34 ft.
2. The values of the delivery parameters obtained by the aircraft special PCM instrumentation system and those obtained with the DIAS method agreed within the measurement accuracy of both systems.
3. During the flight tests it was found that two photographs taken with a time interval between 300 and 350 ms would be most appropriate to the analysis.
4. Although DIAS is able to analyse (by approximation) non-steady state deliveries, it has to be emphasized that the results obtained in those cases must be considered with some reservation.

During the flight tests no gunnery and rocketry attacks were carried out. It is, however, expected that the impact errors for both attack types are within the accuracy mentioned in the previous section.

4.3 Airworthiness of the airborne data acquisition system

Ground-based tests.

To establish the airworthiness of the airborne system the following tests were carried out:
- altitude test
- temperature/humidity test
- vibration test
- electro magnetic interference (EMI) test.

An EMI test with the system attached to the aircraft was also carried out.
Te tests were executed for the prototype system as well as for the series production.

In summary it can be stated that the airborne system has withstanded the tests excellently.

Flight tests.

As is customary when new aircraft configurations are to be certified, the following subjects are investigated:
- structural strength
- flying qualities

*difference between the actual and predicted impact positions.

- flutter
- aircraft performance
- store separation.

Structural strength.

The DIAS centerline pylon nose has to withstand the loads, that will be imposed under the flight condition listed in table 4.

TALBE 4

| acceleration (g) | | | airspeed (kt) | Mach number |
|---|---|---|---|---|
| longitudinal | lateral | vertical | | |
| ± 2.5 | ± 1.5 | -1.5/+7.2 | 720 | 1.7 |

The structural strength of the nose is considerably in excess of the requirement, as stiffness, necessary to obtain a good camera platform, was the dominant factor in determining the dimensions of the construction. Hence, it was decided not to evaluate the structural strength aspects by means of flight tests, but only to demonstrate structural integrity, by flying up to the limits, imposed by the aircraft itself.

Flying qualities.

The location of the DIAS nose is such, that no changes in the distribution of the lift over the wing will occur, nor will the airflow over the elevators be affected. Thus, no changes in the overal flying qualities of the aircraft due to aerodynamic effects will occur.
The mass, added due to DIAS (30 lbs) results in a shift in the centre of gravity of the aircraft, but the shift will be small (less than 0.1 % m.a.c.). Furthermore, the shift will be in a forward direction, which is beneficial for flying qualities.
Based on these considerations it was decided that a special in flight evaluation of flying qualities was not necessary. No anomalies were noted during the flights carried out so far.

Flutter.

Past experience (extensive analysis of various NF-5 configurations, verified by flight tests) has shown that the amount of mass, installed at the centreline pylon hardly affects the flutter behaviour of the aircraft. As the mass addition due to DIAS is rather low, it was decided that no flutter analysis was required.

Aircraft performance.

To establish the increase in drag number, performance measurements were carried out and compared with measurements executed during flights with the normal centerline pylon.
The results of the tests showed that the effect of the DIAS nose on aircraft performance is quantified by an increase of the basic configuration drag number (7) with 5 counts which is negligible.

Store separation.

The change in geometry of the centerline pylon will affect the air loads acting on captive stores. Thus the behaviour of these stores during separation may be affected. To evaluate the magnitude of the change measurements were carried out using the air load measuring store described in (8). The results were compared with data obtained earlier in combination with a normal centerline pylon.
The normal and lateral force components as well as yawing and rolling moment coefficients were identical in both cases.
With the normal pylon, no effect of Mach number on the pitching moment coefficient was present, whereas with the DIAS nose there is. Furthermore with the DIAS nose the moment coefficient is more nose up at low angles of attack and low Mach numbers.
With the knowledge of the separation behaviour of empty centerline tanks (low density) which is most critical (9) and because of the measured small increase of the pitching moment coefficient (0.011) caused by the DIAS nose it has been concluded that the effect of the change in local air flow due to the DIAS nose on store separation is negligible so that store separation flight limits are not affected.

Subsequently demonstration flights, covering the program of the airworthiness test flights (excluding performance items), a "cold soak", followed by flight in a warm, moist atmosphere, while operating the DIAS system, were carried out. A proper operation of the system during the most extreme conditions was demonstrated.

## 5. IMPLEMENTATION OF DIAS IN AN OPERATIONAL NF-5 SQUADRON

Because of the results obtained the RNLAF decided to realize DIAS for "operational" use.
For the present one NF-5 squadron of the RNLAF has been equipped with DIAS.
The squadron has at its disposal a ground-based system and 5 aircraft equipped with an airborne system.
In total 1000 DIAS sorties, consisting of 2000 to 4000 attack runs, will be carried out per year. A large number of targets are available.
Dependent on the results to be obtained during the first half year, more aircraft will be involved and other NF-5 squadrons will be equipped with DIAS.

At the moment the squadron is not yet "DIAS operational", so no more information herein can be given.

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## ABOUT THE AUTHOR

Charles, F.G.M. Hofman joined the National Aerospace Laboratory NLR in 1972 as a research engineer of the "Stability and Control" Department. Currently he is employed in the Department of "Military Operations Research" and is responsible for the set-up of flight test programs to collect data of operational mission data. These programs are often carried out with aircraft from the Royal Netherlands Airforce. He was also manager of the DIAS program.

He received the degree of "Diplom Ingenieur" in electronic engineering from the University of Technology of Aken (FRG) and was an assistant in research at the Department of "Digital Data Analysis" of the before mentioned University.

# VISUAL AND INFRARED SHIP MODELING FOR COMPUTER IMAGE GENERATION*

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ABSTRACT

Programs for generating simulated visual and far-infrared imagery of Soviet combatant ships were implemented on a computer system at the Naval Training Equipment Center. These programs were used in a system definition study to determine the characteristics that a real-time computer image generation system must have in order to satisfy trainer performance requirements for processing capacity and resolution. The implemented system consists of data bases at various levels of detail, visual and far-infrared sensor models, and image generation capabilities that include a flexible set of options for various viewing conditions and special features.

## INTRODUCTION

The Naval Training Equipment Center (NTEC) is developing the Advanced Visual/Near-Visual Submarine Periscope/Electro-Optic Infrared Sensor Simulation (AVEOSS) prototype trainer. As part of the supporting R&D effort, Technology Service Corporation (TSC) implemented general computer image generation (CIG) programs as part of a system definition study to determine the characteristics necessary for the trainer system. The scenario involves the Osa, Kashin, and Kiev Soviet combatant ships viewed through both visual and far-infrared sensors.

Because the most significant parameters in the definition study were level of detail and resolution at varying ranges and aspects, the CIG programs and models had to allow the user complete operational control. To this end, the geometric ship models were constructed from planar surfaces, ranged in level of detail from 500 to 4000 potentially visible edges, and could be viewed from any aspect angle and range with display formats from 512 to 2048 raster lines per TV frame.

This paper describes the CIG programs and data bases implemented at NTEC in terms of geometric data base modeling, visual and infrared models, and frame generation characteristics. The data bases developed use modular, hierarchical construction so that complex scenes can be processed and sensor-ship interaction can be blended with the hidden-surface and shading requirements for image generation. The visual and infrared sensor algorithms include reflectivity models and more complex components for determining the radiant emittance of a surface in the far-infrared spectrum. The sensor models incorporate the effects of ship surface materials and the intervening (user-selected) maritime environment. The frame generation routine employs a list-directed priority algorithm for determining hidden surfaces. Included along with the user-selected parameters for level of detail, range, aspect, resolution, and magnification are options for edge smoothing and smooth-surface shading.

The CIG methodology used in the system is described next, followed by sample imagery of the Kashin and Kiev models taken from a high-resolution Dicomed image recorder. Recommendations for further efforts in data base modeling are given in the last section.

## CIG METHODOLOGY

The system implemented at NTEC (see block diagram in Figure 1) generates shaded computer imagery in three distinct steps. First, a scene (e.g., a ship on the ocean) and the objects composing it are stored in a geometric data base in a meaningful and useful format. Second, the tone (or gray level) of each surface is predicted. Third, the surfaces are projected onto a screen and a shade assigned to each pixel for the surfaces viewable in that pixel.

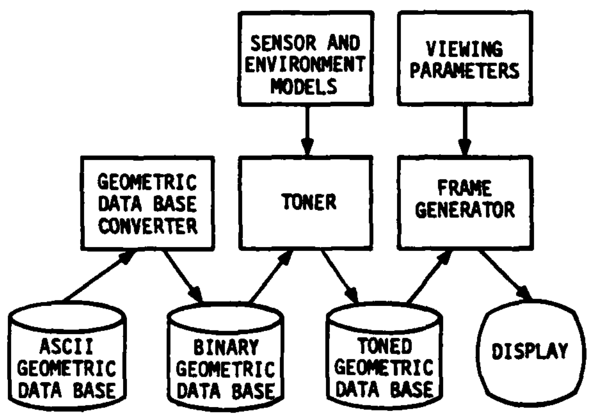


Figure 1. General CIG System and Interface

The geometric data base consists of planar polygonal bounded surfaces defined by vertex points. A material identification code is associated with each surface. Surfaces that are locally coherent are grouped into objects. A list-directed priority scheme employing a tree-structured directory is used in organizing the data base in order to determine hidden surfaces. The data base converter in Figure 1 performs three primary tasks:

*The work leading to this paper was performed under NTEC Contract N61339-79-C-0151.

1. Convert the data base from ASCII to a binary format.
2. Set up a tree-structured directory with pointers to the surfaces.
3. Compute the outward normal of each surface.

Since these tasks are performed early in the process, they do not have to be repeated for each frame generated. Thus, while subsequent processing is repeated as conditions change, data base conversion is performed only once in the life of a data base.

The toning process for visible and infrared sensors is performed independent of frame generation. The toning routine may be thought of as a "black box" which computes, for a given sensor and set of environmental conditions, a single tone for an entire surface or a tone for each vertex of a surface. Material descriptions are associated with each surface to provide visible reflectance, interior conditions, absorptivity, emissivity, surface orientation, and surface roughness. Environmental conditions include solar and sky loading, air and water temperature, and humidity.

The frame generation routine is central to the system. In general, all other elements of the system support the frame generator. With a toned data base and viewing parameters as input, the frame generator outputs a synthetic image via two subprocesses:

1. *Geometric processing*, in which the surfaces of the data base are ordered, translated, and rotated relative to the viewer, and then clipped against planes bounding the field of view.
2. Raster processing, in which each raster is generated by determining the viewable surfaces in each pixel and then assigning the appropriate shade for each pixel.

## Geometric Data Base Modeling

Basic Geometric Considerations. The basic primitive used to build the geometric model is a one-sided polygonal bounded surface that can be convex or concave. It is defined by a list of vertex points, ordered counter-clockwise from the viewable side. Since each surface is planar, it possesses a unique outward normal. Locally coherent surfaces are grouped together to form an object. At the object level, a number of useful operations may be performed, most notably redefinition or specification of the level of detail and rapid elimination of an object's surfaces from the field of view.

Many of the planar surfaces in a ship data base are patchwork approximations to curved surfaces. To perform curved-surface shading and make the surfaces appear smooth, the surface normal must be supplemented by defining an outward normal for each vertex. Although in some cases, such as the ship's hull, the actual contour cannot be determined, selected points on the contour can be located. In such a case, a vertex normal can be approximated by averaging the normals of surfaces that share the common vertex. In many cases, simple geometric entities such as spheres, cylinders, and cones (either complete or truncated) can be originally specified for objects. The objects can then be transformed into a patchwork of surfaces.

The use of geometric entities which can be parametrically specified during data base development impacts CIG in two significant ways: 1) the contours are known exactly and, consequently, so are the vertex normals; 2) the level of detail needed to represent an object at various ranges is easily adjusted. As the chosen level of detail for a data base increases, so does the fineness of the patchwork used to approximate the curved object. For example, for the tubular superstructure of a tower, cylindrical approximations can be used for high detail at close range, whereas only a single strip is needed for lower levels of detail.

Data Base Organization. Local surfaces listed by their vertices constitute the basic representation of an object in a geometric data base. However, the overall design of a geometric data base can significantly impact CIG system capabilities. In other words, while the basic geometric data are necessary for generating computer imagery, the organization of the data base may help to solve problems such as hidden-surface determination as well as allow the structured, modular development of complex scenes.

The hidden-surface problem encountered in the frame generation process is essentially solved a priori by using a list-directed priority scheme when developing the geometric data base.[1,2] The drawbacks of this solution are that it somewhat restricts the arrangement of surfaces and objects and increases the cost of data base development. On the other hand, it decreases the cost of frame generation because surface masking priority is already determined and thus does not have to be repeated in other CIG routines such as specular reflection and shadow generation.[3]

The list-directed priority scheme uses two distinct methods to establish the priority list. First, all surfaces comprising an object are listed according to their inherent masking priority within the object such that no surface may mask any other surface listed before it, regardless of the viewing position. Inherent masking priority restricts surfaces from intersecting each other anywhere but at their edges. For a convex object, any surface order is acceptable because no surface of a convex object will ever be masked by another surface. (Note: Since surfaces are one-sided, surfaces facing away from the viewing position are not considered masked.) For a concave object, inherent masking priority may not exist, in which case the object can be divided into smaller objects to solve the masking problem.

The second method used to establish the priority list of all surfaces is to subdivide the scene into objects. Once the surfaces within each object have their inherent ordering established, the remaining task is to sort the objects. To do so, a tree structure was implemented which can modularly create a complex scene by combining simple objects to form more complex objects. Or, as illustrated in Figure 2, a complex scene (such as ships at sea) can be broken down into simple objects and geometric primitives.

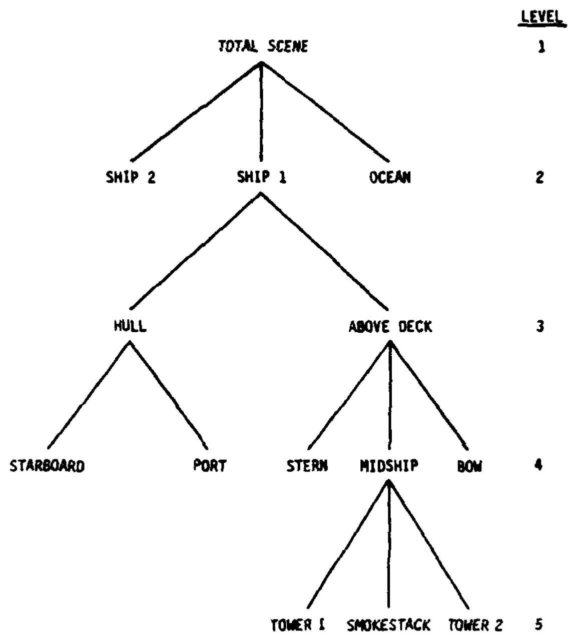


Figure 2. General Tree Representation of Ship Geometric Data Base

To fully understand the tree structure used, definitions of some terms and relationships are necessary. A node is any point on the tree and consists of one or more objects grouped together. A node's descendants (subnodes) are all nodes subordinate to it. The node's closest descendants (i.e., those in the next immediate level) are designated as the node's children. A node is considered a parent to its children and an ancestor to all its subnodes/descendants. Nodes sharing a parent are siblings. Thus, in Figure 2, the node TOTAL SCENE is an ancestor to all nodes of the data base and the parent of its children SHIP 1, SHIP 2 and OCEAN, which are themselves siblings. No other direct relationships are defined and no significance is attached to the relative levels of two nodes except as to their being descendants, ancestors, or siblings. For example, it is of no consequence that the nodes for the PORT side of the hull and the MIDSHIP section above the deck are both at level 4. The number of levels, nodes of the tree, and children of any node are unlimited. A node with no subnodes has only the geometric primitive surfaces as its children.

For each node, priority tests determine the ordering of its children. Once the children (siblings) have been ordered, the ordering of all their descendants (with respect to the siblings) is established by their transitive properties. For example, if SHIP 1 masks SHIP 2 for a particular eye position, so do all descendants of SHIP 1. For this ordering scheme to be correct, all siblings must be pairwise linearly separable by a separating plane. Stated another way, a node may not intersect the convex cover of any node other than its ancestor or descendant. If such an intersection does occur, the masking relationship between a node's siblings and its descendants is not transitive and thus the masking relationship between unrelated nodes is not known. For some situations, this nonintersection rule may be relaxed during data base development if it is known that the eye will be restricted to certain regions of space, such as the upper hemisphere (i.e., above the ground or ocean).

Figure 3a illustrates a simple, 2-D case in which the nodes have been incorrectly formed and thus are not linearly separable. B(1) and B(2), separated by a dashed line, have been combined to form their parent node B. However, since this parent is not separable from node A by a plane, from certain viewing positions part of B will mask A and A will mask some other part of B. In Figure 3b, A(2) (which is B(2) in Figure 3a) has been combined with A(1) to form parent node A. In this case, nodes A and B are linearly separable and thus the masking relationships are transitive. Hence, planes to separate the nodes may be defined within the data base and used to order objects once viewing position has been specified. During frame generation, A and B will be ordered, followed by A(1) and A(2). If further subdivision takes place, ordering continues until all objects are ordered. At that point, the masking problem will be solved because each object's surfaces were previously listed by their inherent masking priority.

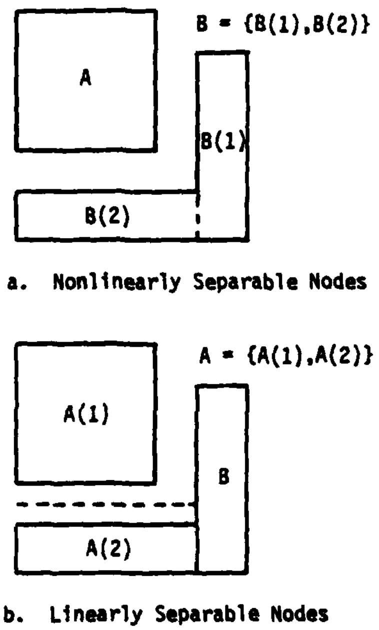


Figure 3. Node Formation

The geometric data base is stored as a separate directory and a surface list. The directory represents each node by a unique number and contains general, relevant information associated with each node (such as its children's node numbers and separating planes as well as the node's local origin and bounding box). The surface list contains each object's surfaces in sequence, along with vertex lists, surface and vertex normals, material descriptors, and an associated object node number. Whereas the surfaces of an object must be listed sequentially, the objects themselves can be listed in any order. When the data base is converted from ASCII to binary format, pointers from the directory to the first surface of each object in the surface list are established to provide random access to any object.

The tree-structured directory offers more than just a solution to the hidden-surface problem. For instance, any portion(s) of the data base can be viewed by specifying desired nodes. By default, the total scene is displayed. In addition, the data base can be significantly modified through the directory. For example, by changing the local origins, objects or large nodes (such as an entire ship) can be moved. However, when modifying local origins, the separating planes between sibling nodes may have to be redefined, and motion must be restricted so that nodes do not intersect.

## Visual and Infrared Toning

Toning is the CIG phase in which electromagnetic models are implemented to predict a gray level for a surface, or a portion of it, based on the sensor model, environmental conditions, and surface characteristics. The toning models are essentially independent of each other and of frame generation. For the visible band, gray levels correspond to the percentage of total light reflected. For the infrared band, gray levels correspond to the emitted and reflected infrared flux density. The predicted gray level replaces the material code for each surface or each vertex of a surface in the geometric data base.

The current implementation for the visual model is based on Lambert's diffuse reflection. For this model, the tone computed is independent of eye position and is based on the cosine of the angle between the surface normal and a light source (e.g., the sun). An additional component is included to account for the sky as a light source.

The infrared model represents a more complicated situation in which material type, internal temperature loads, air temperature and humidity, and the contributions of surrounding bodies are major factors in predicting gray levels. A further complication is that, while the model is diffuse and thus independent of viewing aspect, attenuation due to range can be significant. The following discussion explains the infrared model in more detail.

Thermal Emission. The radiant emittance (the power per unit area of a black-body emitter) with a spectral band bounded by minimum and maximum wavelengths $\lambda_1$ and $\lambda_2$, respectively, is given by

$$W = \int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5} \frac{\lambda d}{\left(e^{c_2/\lambda T} - 1\right)}$$

where T is the absolute temperature of the body, and $c_1, c_2$ are constants. For surfaces at or near room temperature, a substantial amount of thermally emitted radiation is in the 8 to 12 μm spectral band. In addition, a surface reflects thermal radiation from other, nearby emitters such as the sky and water. Thus, the total emitted energy from a surface is approximately the sum of its own thermal emission and the reflected energy of its surroundings.

Infrared Gray Level Prediction. The gray level of a surface is directly proportional to the surface's radiant emittance. To predict a surface's radiant emittance, its absolute temperature at any arbitrary time must first be predicted. Surface temperature is a function of the thermal properties of the material, the instantaneous temperature of the surroundings, and the previous temperatures of the surroundings.

In the infrared toning model, an environmental file is set up for the scene. This file contains parameters such as longitude, latitude, day of the year, data base orientation with respect to North, and hourly air temperatures for the 24 hours prior to the "day" the ship imagery is being simulated. From these parameters, the radiative and convective heat load on the exterior surface at any time can be determined. The interior surface is assumed to be exposed to a constant interior ambient temperature. The conductive path between the exterior and interior surfaces can be modeled as an equivalent RC electrical network. The surfaces in the ship data base are assumed to be metal plates, and the equivalent RC network model contains eight nodes, as shown in Figure 4.

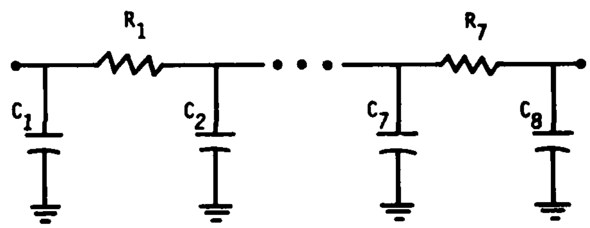


Figure 4. RC Network Model for Thermal Conduction through a Metal Plate

To determine the precise temperature at each node requires an eighth-order differential equation. An approximation is obtained by solving a system of eight first-order linear difference equations. Thus, a reasonably accurate calculation can be obtained for the exterior temperature of all surfaces in the data base.

Gray levels are predicted in two steps. First, the environmental data are used to calculate the exterior temperature of metal plates whose normals are oriented in twelve standard directions, and a look-up table is generated. Second, each surface in the data base is addressed and its normal vector is compared to the twelve standard directions to interpolate the surface temperature and add in the reflected infrared energy.

*Atmospheric Attenuation.* Before the gray level is assigned, the effect that atmospheric attenuation of surface emittance has on the gray level is calculated. Atmospheric attenuation depends on the field-measurable parameters of temperature, relative humidity, range, and visibility. A scaled-down version of the LOWTRAN 4 atmospheric transmission model developed at the Air Force Geophysics Laboratories is used. The maritime aerosol model and a horizontal transmission path are assumed. The gray level assigned is based on the attenuated emittance "seen" by the sensor.

## Frame Generation

*User-Selected Parameters.* A number of parameters/options are available to the user for generating imagery in many formats and for many conditions. The user can select:

1. Data base and associated level of detail
2. Eye position in x,y,z scene coordinates
3. Aim point (i.e., image center) in x,y,z scene coordinates
4. Frame size--number of rasters, number of pixels per raster
5. Field of view--horizontal and vertical in degrees
6. Rotation in degrees
7. Special features for earth curvature, smooth-surface shading, and edge smoothing.

The frame size and field of view chosen dictate the sampling resolution per pixel. Field of view is also inversely proportional to magnification. For a given frame size, objects remaining in the field of view will subtend more pixels as the selected field of view decreases. For the periscope modeled, magnification of 1X corresponds to a 48° field of view, 6X to 8°.

*Geometric Processing.* Geometric processing is a preprocessing step to raster processing. It comprises all operations by which the potentially viewable surfaces are ordered and oriented relative to the eye.

As explained earlier (see Geometric Data Base Modeling), objects are ordered through tree traversal, during which sibling nodes are compared via separating planes. For a pairwise comparison, the node on the same side of the separating plane as the eye has priority over the other node. Since each object's surfaces are presorted, all surfaces are ordered when all objects have been ordered.

All surfaces are then clipped by the planes of the field of view using a reentrant polygon clipper.[4] The clipping process can be rapidly accelerated by determining whether the bounding boxes of the objects are totally inside or outside the field of view. If the effects of earth curvature are to be simulated (so that the ship drops off the horizon), the surfaces are also clipped against an ocean plane.

Finally, all remaining surfaces are translated and rotated relative to the eye coordinate system, in which the origin is at the eye and one of the major axes lies along the line of sight. The resulting edges are stored in a general edge list for raster processing.

Note that the surface vertices are not transformed to 2-D screen coordinates (normally a perspective transformation) at this stage. Instead, the transformation is performed during raster processing because a nonlinear projection such as a cylindrical or spherical projection[5] requires the original 3-D information. For the CIG system discussed in this paper, only the perspective projection is used.

*Raster Processing.* The list-directed priority scheme considerably simplifies raster processing in that no further testing is needed to determine which surfaces may mask other surfaces. Frame generation proceeds one raster at a time, top to bottom. As each raster is processed, the points at which all edges enter and exit and raster are maintained. The edges are then projected onto the screen.

Each raster is generated pixel by pixel, left to right. For each pixel processed, a stack is maintained and updated to indicate which surfaces in the pixel, delimited by their edges in the raster, are potentially visible. If no edges of the top surface in the stack lie in the pixel, the pixel is completely shaded by that surface. If the surface has a uniform shade, the predicted surface tone is used. If the surface shade varies between vertices, Gouraud shading[6] is applied.

Whenever edges are visible in the pixel, aliasing effects are reduced by an edge-smoothing technique which assigns a shade to the pixel based on the relative amount of area of each surface in the pixel. The area of each surface is calculated by a simple summation of triangles and rectangles outlined by the surface edges and borders of the pixel. This technique does not reduce aliasing effects as completely as Catmull's integrator algorithm[7] because it only estimates portions of any surface other than the top surface that are actually visible in the pixel. However, this approach requires less computation and significantly reduces the stairstep effect observed in raster graphics.

## SHIP MODELS AND IMAGERY

The major cues for recognizing ships are the edge content and distinguishable shapes produced by contrasts in gray shades. Although texture is an important recognition cue in many simulations, it is of little importance for ships because they usually have dull gray or black overcoats of paint. The ship's silhouette provides the primary sources of contrast; however, certain areas of the ship provide other contrast sources (e.g., hull concavities and "hot spots" in infrared simulations).

The overriding goal of data base modeling was to produce the ship's general outline along with those portions of the superstructure which add detail to the outline. In addition, we modeled major objects which blended in with the rest of the ship from a broadside view but were prominent from a quartering aspect. In line with the hierarchy illustrated in Figure 2, data bases were developed by dividing each model into its major components and then subdividing until all objects of interest were defined and their surfaces could be listed by inherent masking priority.

Emphasis was also placed on modeling objects so as not to display unwanted edges, such as those generated by planar patches used to simulate curved surfaces. Smooth shading was attempted on selected portions of the ship to demonstrate its effects.

Data bases for each ship range in level of detail from approximately 500 to 4000 potentially visible edges. Data bases of high level of detail were developed first, followed by data bases of progressively lower levels. This approach was based on the assumption that it is easier to remove than to add detail. The three methods implemented to achieve the lower levels of detail were 1) planar patches were reduced in number and increased in size so that less or no curved surfaces were simulated, 2) objects or surface detail not contributing to the broadside silhouette or other major areas of contrast were eliminated, and 3) small objects were either removed or grouped to form major, simplified objects.

Figures 5 through 8 and Figures 9 and 10 are, respectively, visual images of the Kashin and Kiev high-level-of-detail models. These images illustrate the complete 3-D nature of the models. The Kashin model consists of 63 objects and 1150 surfaces; the Kiev model of 103 objects and 2300 surfaces. The images were generated on the VAX-11/780 computer at the Experimental Computer Simulation Laboratory of NTEC, and were photographed with a Dicomed D-47 image recorder. Options for edge smoothing and smooth shading were used.

For the Kashin, the midsection was emphasized because of its prominent structures such as the smokestack and radar towers. In Figure 8, the main radar tower's complex tubular structure illustrates the detail that can be portrayed. In addition, the hull was emphasized because of its distinctive shape and the line that runs along much of it, both of which are significant recognition cues. (The hulls of U.S. destroyers are flat from bridge to stern.)

For the Kiev,* importance was placed on modeling the dominant superstructure and the irregular, asymmetric hull with its concave sections. As was done for the Kashin, radar antennas were modeled because they are distinguishable features. The top-sail radar (dark object above the bridge) was modeled with especially high detail using a gridwork of tubes.

*Although the figures show the Kiev as equal in size to the Kashin, the Kiev model is actually twice as large. The field of view for the Kiev images was halved.

## RECOMMENDATIONS

Whereas the CIG software at TSC needed only minor modifications to handle the large geometric data bases and the maritime environment, the geometric data base modeling required much effort because of the manual, labor-intensive techniques used. Ship measurements were made from line drawings and entered into the geometric data base via keyboard. Most of the validation consisted of visually inspecting sample computer-generated imagery. Tasks such as ordering surfaces by their inherent masking priority and choosing the detail to be used for modeling objects were generally performed by the modeler.

An interactive data base editor with the proper graphics hardware could significantly reduce the throughput time for developing and validating a geometric data base. Data could be entered via digitizer tablet or keyboard and displayed on a vector graphics terminal. With cursor control and a convenient set of command capabilities, the modeler could manipulate the data on a vertex, surface, or node level to achieve any desired geometric configuration. Operations useful to the modeler could range in complexity from simple translation and rotation routines to automatic surface ordering within an object, and even to automatic object subdivision to resolve surface masking-priority conflicts.

## ACKNOWLEDGMENTS

Acknowledgments are extended to Warren Stone of TSC for his work on data base modeling, Jeri O'Donnell of TSC for her editorial work on this paper, and Dennis Mistoler of NTEC for generating the ship imagery.

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Figure 5. Broadside View of Kashin

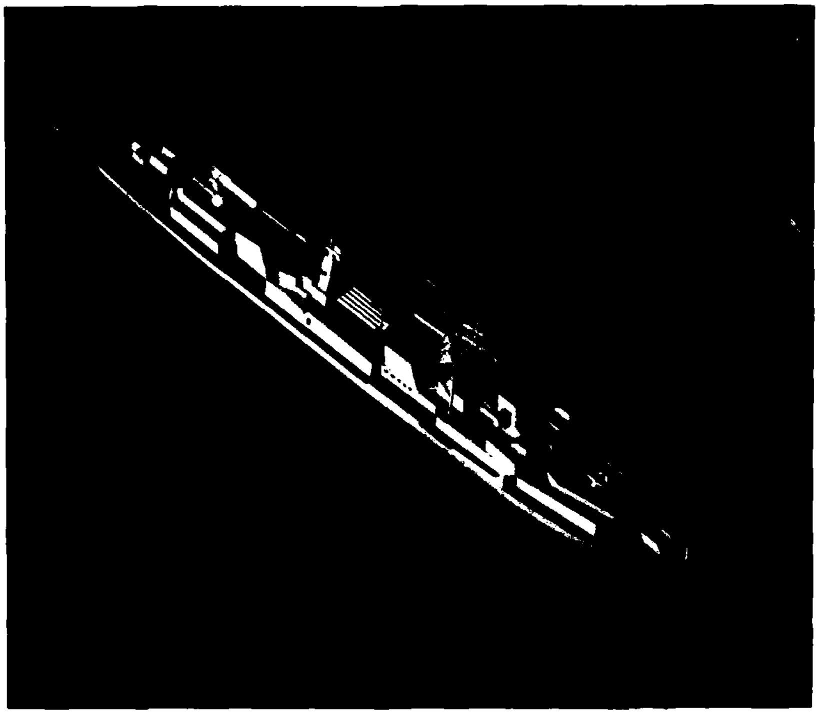

Figure 6. Aerial View of Kashin

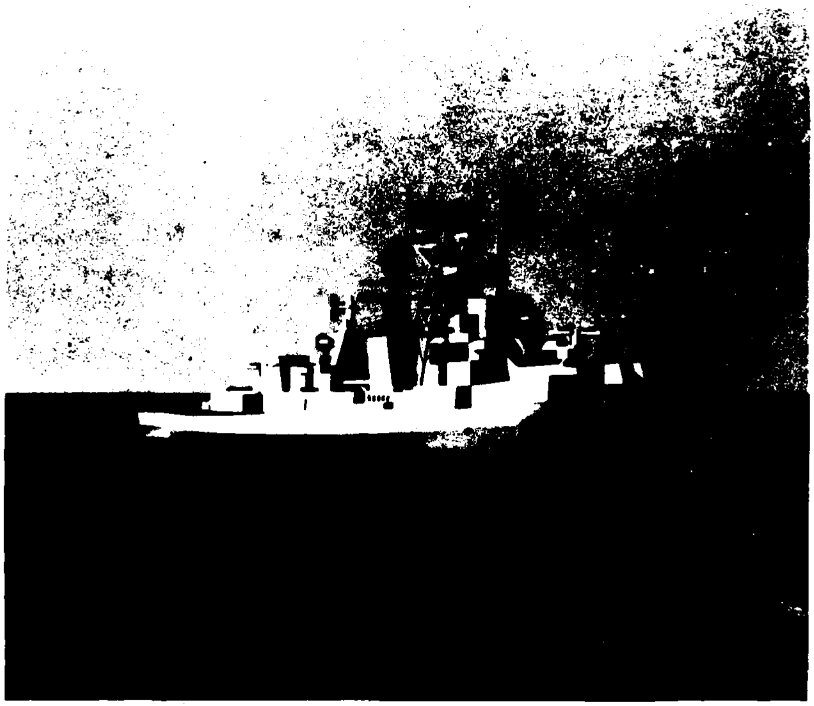

Figure 7. Quartering View of Kashin

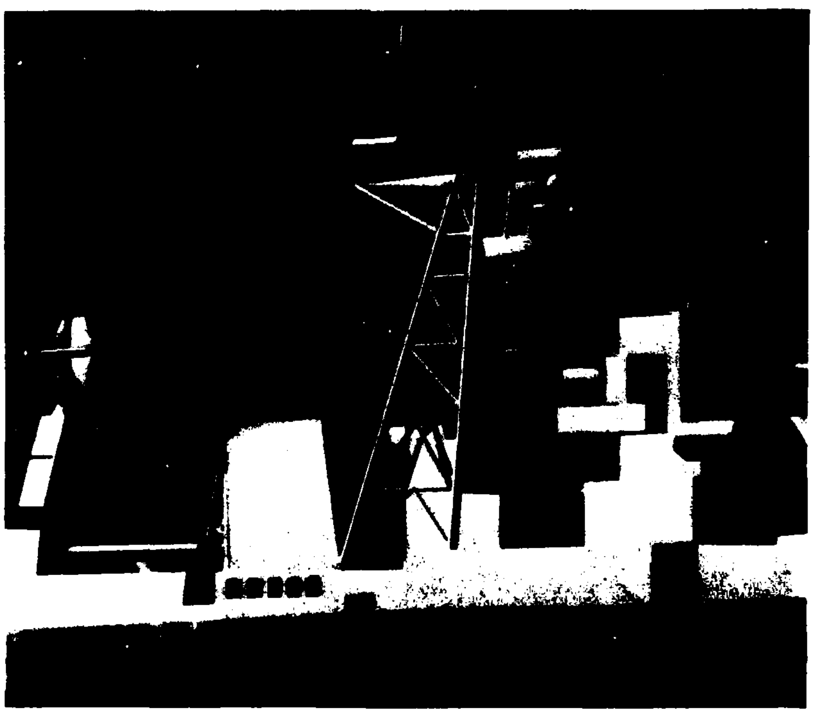

Figure 8. Close-Up of Kashin Midsection

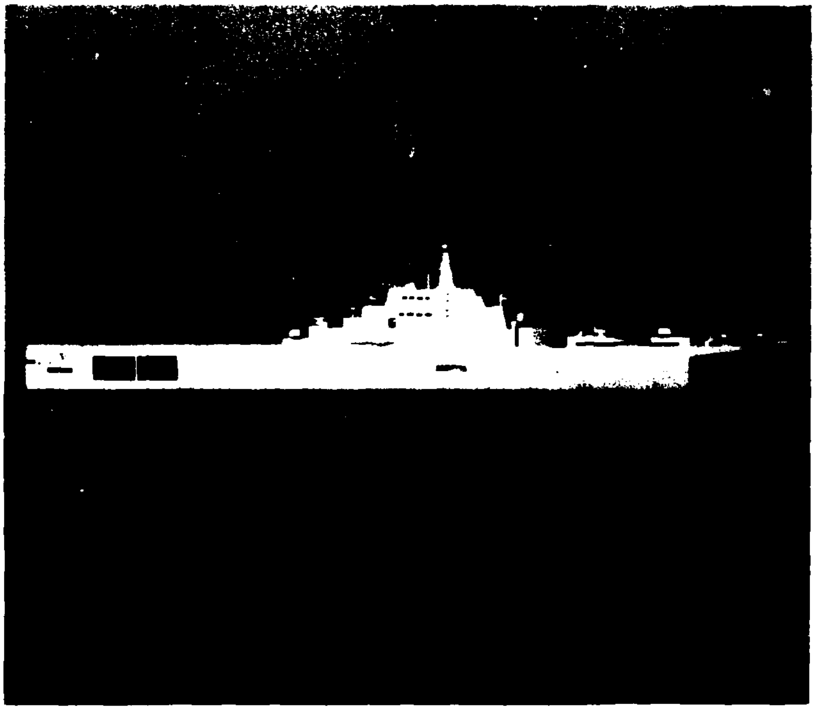

Figure 9. Broadside View of Kiev

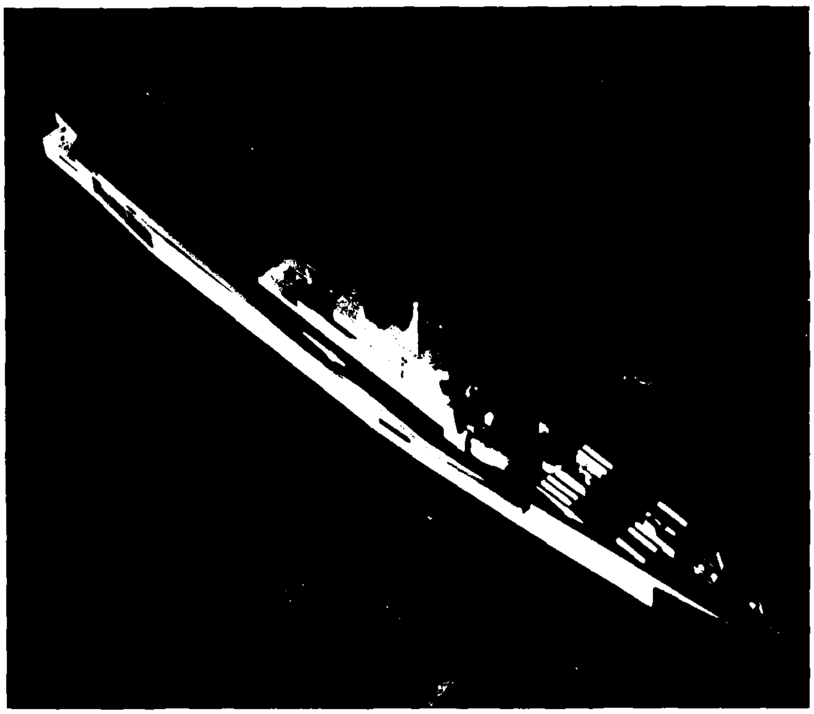

Figure 10. Aerial View of Kiev

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# USER ACCEPTANCE OF R&D IN NAVY TRAINING: THE PROBLEM, MAJOR CONSTRAINTS, AND AN INITIAL MODEL OF THE ACCEPTANCE PROCESS*

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ABSTRACT

The problem of operational user acceptance of naval training R&D studies and training devices is presented. A number of constraints on acceptance are described, including deficiencies in motivational conditions, deficiencies in social role assignments, deficiencies in official organizational policy and structure, inadequate defense R&D contracting methods, lack of integration of the user into the trainer system acquisition process, other-than-rational user responses to R&D studies in training, and deficiencies in training device design. A preliminary model of the acceptance process is presented. Finally, the degree of physical fidelity necessary for operational acceptance and training effectiveness is discussed. It is concluded that this paper and related recent work form a basis for the development of alternative approaches to solving the user acceptance problem.

## INTRODUCTION

Scientific research and development (R&D) is a major institutionalized means for creating improvements in military technology. The R&D community creates these improvements not only by constantly advancing the technological data base, but also by introducing that technology into fleet operations. In fact, the force for change from "technology push" (12) by R&D agencies has been traditionally stronger in generating operational requirements than that from "requirements pull" by the operational fleet who formally establish Navy requirements (28). Training technology has also advanced rapidly in the last decade. However, there is considerable evidence that training organizations are reluctant to accept the introduction of R&D studies. In addition, acceptance of specific training devices is a major problem. There has been very lit[illegible] investigation of the factors influencing the acceptance of new training methods introduced by R&D studies. R&D has generally fulfilled its role in creating the potential for useful changes in operational training, but has not developed an adequate model to assist in how change should be managed. Basic organizational and human resistance to change has remained stable, whereas the rate of change itself has greatly increased. A major task of training R&D, therefore, is to develop managerial methods for the successful planning and implementing of changes in training technology.

### Importance of the User Acceptance Problem.

Improved acceptance is especially critical now for several reasons:

1. Significant advances in effective training technology remain to be incorporated into the Fleet. Computer training technology (3) and maintenance training (23) advancements are two major areas of "gaps" between available technology and its applied use. In addition, further R&D studies need to be performed to evaluate and improve currently implemented training systems.

2. A variety of low-cost, low-fidelity approaches to training system design are now under development. The degree of physical fidelity (realism) has been shown to be the single most important variable in gaining user acceptance (7). However, the current practice of "buying" user acceptance of simulation training at the (high) cost of increased physical fidelity is being questioned. Thus, the loss of acceptance from fidelity sources requires improved acceptance conditions from areas other than fidelity. This issue will be discussed in a subsequent section.

3. There is an increasing need to introduce and to have accepted training improvements as early as possible. Over the past decade the time to acquire a major weapon system (and related training materials) has steadily increased (11). In the current environment of international tension, it is imperative that the user be in a position to move the acquisition process along and to incorporate training improvements as rapidly as feasible.

4. Training technology will be increasingly integrated into ongoing fleet operational systems. With the advent of portable, rugged, and compact training systems has come the possibility of training aboard ship (called onboard training or OBT) -- either in the form of original or refresher training (e.g., landing refresher trainers in the pilot ready room as currently envisioned by NAVTRAEQUIPCEN - see 25). Recent shipboard weapon system design with new class destroyers includes provisions for embedded training devices used to support team training. The success of the OBT concept will depend critically on acceptance of this concept by fleet personnel.

5. An especially critical problem of accepting flight simulators as flight hour

substitution devices now exists. In a document (8) issued by the Chief of Naval Operations (CNO), authorization and plans for achieving a 25% reduction in Navy flight hours (and huge fuel savings) by the end of FY 81 were stated. The flight simulator was viewed as a potential flight substitution device by higher command echelons of the Navy. Local training commands, however, have continued to view the simulator as a means for augmenting rather than replacing aircraft training. This discrepancy between perceptions of the purpose of the device is a major reason for the documented underutilization of aviation training devices and the consequent failure to demonstrate cost savings through flight hour reductions (Navy Audit Review, 24).

6. Operational tasks and equipment are becoming increasingly complex (14) and human error correspondingly probable and costly. Thus, greater reliance of training substitutes for operational environments will be necessary, for a variety of both high-cost and low-cost forms of training.

Focus of this Report. The focus here is on acceptability of new training methods by training system users. Acceptance of training, however, is regarded as a tri-service problem and a conceptual model of the acceptance process needs to be developed for tri-service use (see below).

A second major focus is on the factors supporting the introduction of R&D studies into training organizations, in contrast to subsequent testing, installation and institutionalization of the change into ongoing fleet training cycles. Obviously, successful acceptance at the beginning will make subsequent implementation much more likely. Although this report will often illustrate the process of acceptance in terms of an R&D study with a training device, the successful introduction of R&D studies in all operational training areas is of prime concern. Where devices are mentioned, they will be aviation training devices (ATDs) due to the authors' experience in this area and the high cost of these trainers. Underutilization and even non-utilization of ATDs has been documented for both Air Force (7) and Navy (20) devices. These two sources are the only studies that have systematically reviewed the effects of different user attitudes and device features on utilization of ATDs. Many of the observations made by these earlier reports regarding ATDs were supported herein as also being relevant to the acceptance of R&D studies. Additional observations have been provided in the present paper regarding acceptance of R&D, many of which would seem to apply as well to ATD acceptance. Further, a model for user acceptance of R&D has been developed which represents a beginning effort to integrate theoretical literature from the general area of organizational change with the earlier and present observations from ATD and R&D field implementations.

Perspectives on Acceptance and Change.

1. Who has the acceptance problem? There is a natural tendency to focus on the operational user when thinking about acceptance of R&D. If R&D studies or results are not accepted, the user may be labeled as resistant to change. The view here is that the user can take neither credit for acceptance nor blame for the rejection of R&D efforts. Instead, acceptance depends on a large number of factors influencing training at the individual, group, organizational, and CNO levels. Acceptance is a training system output and therefore the system should be the target for change.

A major purpose of this report is to identify a number of general constraints on acceptance, only some of which exist at the operational user level.

2. Is high user acceptance the goal of R&D efforts? User acceptance is a continuous variable ranging between the extremes of complete rejection of an innovation to complete acceptance. It is apparent that even the most effective and economical training program or device can have no value if it is rejected (unused). However, complete acceptance of a training method is not necessarily desirable either, since acceptance also may be based on reasons other than effectiveness and economy. Caro, Shellnutt, and Spears (7), e.g., have made an important distinction between acceptance of a device as used and acceptance of a device as it was designed to be used. In flight training, there is considerable evidence that even when devices are well accepted, their capabilities are often underutilized (29). Operational Flight Trainers (OFTs), e.g., are often highly accepted only as Cockpit Procedures Trainers (CPT). The primary goal of R&D efforts is not on maximizing user acceptance, but on maximizing organizational effectiveness and economy of the training organization.

3. Is the proposed change always desirable? The perspective taken here is that, in specific R&D studies planned with a particular user group, change introduced by the R&D should only be considered after careful diagnosis of the existing training program. Thus, R&D scientists are not to be labeled only as "change agents" but also as "interventionists", a term used by Argyris (2) to characterize a person who intervenes to diagnose an organization's effectiveness, but who does not necessarily follow through as a change agent.

Some R&D studies are ill-conceived; appropriate diagnosis may reveal that there is no training problem as originally conceived, or that the proposed R&D effort is irrelevant to correcting the identified problem, or that the original R&D problem is not significant. Or there may exist a variety of constraints on acceptance which make the study infeasible. These constraints on acceptance are the most compelling reasons for deciding not to introduce change, since almost all training programs could stand some improvement and almost all R&D studies can be (and usually are) adapted to become more relevant to the needs of the local operational group. The rational approach to R&D planning includes the option of not doing R&D studies where a variety of constraints on acceptance of change makes the study exceptionally risky or infeasible. These constraints which exist at all levels of the Navy training command structure, will be described in detail below.

4. To increase acceptance, should the man or the machine be changed? In traditional human

factors engineering, there is a focus on how man interacts with machines (e.g., training devices). To "perfect" the interaction, a scientist can attempt to change either the man or the machine. One approach emphasizes changing the man through "attitude engineering" to increase acceptance of device features existing in current trainers. An apparently more common approach is to focus on the design characteristics of the training machine, especially in terms of physical fidelity or realism. Both approaches need to be included in any comprehensive framework of the acceptance process. In addition, the framework must include "man-man" interactions among users, sponsers, and R&D personnel throughout the entire training system acquisition process, from introduction of initial R&D studies, through design reviews, initial device evaluations, and subsequent training support. Grace (15), in her 1979 presidential address before the Human Factors Society, has pointed out that human factors specialists' have traditionally overemphasized machines, devices, and systems, relative to human interaction problems in the design, development, and use of these machines.

5. Is a scientific approach to the problem of user acceptance possible? Some may resist the idea that science can be used to analyze and actually influence something so apparently nebulous and subjective as "acceptance". Although the state of science is not well developed in the acceptance area, there are some theoretical and empirical bases for influencing levels of acceptance. An initial step in the scientific approach would be to document the extent of variation of acceptance found in various aspects of naval training. Factors that influence acceptance would subsequently be identified, described, and prioritized for different applications. Then improved metrics for these factors would be generated. A conceptual framework consisting of these factors and their relationships to one another would be developed to understand the process of acceptance and to use as a basis for predicting acceptance levels in particular situations. Some of these factors have predictable, but uncontrollable consequences on acceptance levels; other factors are controllable by those with influence in the training command structure. The R&D community can become more proficient at managing the introduction of training innovations by applying those factors that can be controlled to influence acceptance.

Organization of this Report. The remainder of this paper is organized into four major sections:

1. Terminology of user acceptance
2. Major constraints on acceptance
3. Conceptual framework for acceptance
4. Issues in user acceptance

## TERMINOLOGY OF USER ACCEPTANCE

Definition of the User. The usual focus on acceptance is on the operational user -- the level at which a training device or system is operated or maintained. However, in terms of the successful introduction of an R&D study, acceptance must exist on at least two additional levels -- the sponsor or funding level, and the technical or scientific level responsible for immediate management of the R&D study. If acceptance depends upon several levels of users, an overall metric of acceptance would include input from each of these primary users. The role of each user would reflect his major expertise and needs at each level. Thus, acceptance would be maximal when the R&D work was seen as: (1) credible by the operational user who uses his operational expertise to judge the training value of the R&D work; (2) affordable by the sponsor user who uses his cost-benefit analytic expertise to judge the value of the proposed work in terms of funding requirements of competing programs; and (3) researchable by the scientist user who uses his technical expertise to judge the scientific value of the work. Unless the subsequent text refers specifically to the sponsor or the scientific user, it should be assumed that the user is the operational one.

Definition of Acceptance. At the scientific user level, there are well developed rules or validity factors for accepting as worthwhile a proposed R&D study (cf., 6). At the sponsor user level, there also exist established procedures, federal regulations as well as statutory proscriptions to judge the acceptability of a study in terms of funding limits, appropriate funding appropriations, service priorities within funding categories, fiscal year time constraints on obligation, expenditure of funds, etc. At the operational user level, however, the criteria for acceptability typically are not based on scientific, regulatory, or statutory grounds. The criteria for acceptance are based mainly on a tradition which requires the user to make primarily subjective determinations of training value. Subjective opinion will undoubtedly continue as a primary measure of acceptance. Although high subjective acceptance of training methods does not guarantee optimal training value, it is certainly true that an absence of subjective support will reduce the use of methods that may be highly acceptable to both scientific and sponsor level users.

A complete operational definition of acceptance will include all three user levels. In addition, within each user level, there may be several levels of acceptance of change (as modified from Hersey & Blanchard, 16) that can take place:

1. Individual knowledge of an alternative training method.
2. Individual attitudinal commitment to the alternative.
3. Individual behavioral commitment to the alternative.
4. Group behavioral commitment to the procedures called for by the alternative.
5. Organizational/Institutional policy commitment to the alternative.

This expanded definition of acceptance adds two important perspectives to the attempts of R&D to introduce behavioral changes in training practices: (1) failure to obtain behavioral change, at either the individual or group level does not necessarily mean that no change in knowledge or attitude has taken place. These "lower level" changes in knowledge and attitude can provide an important basis for subsequent attempts to obtain behavioral commitments; (2) even change in the form of behavioral commitment may fail to have longer term impact if the innovation does not become institutionalized into the organization's training policies.

Finally, each of these levels of acceptance are continuous variables. Thus, the R&D scientist should not expect to obtain, nor the user feel compelled to provide, unqualified acceptance. It is essential that the user understand that his "acceptance" of an R&D study does not necessarily constitute complete agreement with the proposed change. He should accept, however, the responsibility to honestly attempt to evaluate the training consequences of the implemented change.

CONSTRAINTS ON OPERATIONAL USER ACCEPTANCE

An analysis of the acceptance problem from a systems point of view reveals several kinds of constraints that mitigate or even prevent acceptance of an R&D study or of an ATD. These constraints exist at all levels of human behavior, including the personal, social, and organizational levels of the Navy. Listed below are several major kinds of constraints on acceptance. Although there is some overlap between these various constraints, they do appear to circumscribe the classes of limitations that would need to be considered (and further developed) in any comprehensive treatment of the acceptance process.

1. Deficiencies in User Motivational Conditions.
2. Deficiencies in User Role Assignments.
3. Deficiencies in Official Navy Policy and Structure.
4. Inadequate Defense R&D Contracting Methods.
5. Inadequate Integration of the User into the Weapon Systems Acquisition Process through Participative Management (PM).
6. Other-than-Rational User Responses to R&D Studies and to ATDs.
7. Deficiencies in Training Device Design.

Deficiencies in User Motivational Conditions. It is axiomatic that there must be some personal motivational basis for the acceptance of an R&D study or a new ATD. Adams (1) has recently stated that one of the five major learning principles on which ATDs are (or at least should be) designed and used is trainee motivation to perform the task. He refers to this principle as "customer acceptance". While it is true that the trainee's motivation to practice is important, the more crucial training element for both the acceptance of R&D studies and the use of an ATD itself appears to be the instructor. If the instructor fails to accept the innovation, it will not reach the trainee. Moreover, the instructor's attitudes and role modeling play crucial roles in motivating the trainee to use an ATD (cf., 7). It is also the instructor who is in a position to commit himself to implementing the training methods proposed by the R&D.

An analysis of the motivational conditions commonly found when instructors participate in R&D projects reveals serious deficiencies. These include:

1. Little or no official recognition (via, e.g., fitness reports, acheivement awards) is given for instructor contributions to R&D. As a result, the R&D is perceived as a low organizational priority and unrelated to their position in the Navy.

2. Incentives other than official recognition are also deficient. Although the instructors are essential to implement the study, they receive little credit for successful outcomes.

3. Participation in R&D often increases the total workload of users such that: (a) abnormally long and/or time-stressed periods are required to accomplish the job; (b) participation in R&D threatens performance on other tasks (often more critical in terms of fitness reports, advancements, etc.) due to time taken from these tasks for R&D assignments. Thus, R&D may be viewed by users as a work overload as well as a threat to their position in the Navy.

4. R&D studies are sometimes perceived by instructors as an assault to their professional status. First, there are ways to significantly improve training which users feel they should have implemented but did not. Thus, R&D can threaten the users' status as training designers. Secondly, some training operations (e.g., evaluating and diagnosing student performance, providing remedial practice) that the instructors feel pride and security in being uniquely qualified to perform can be proceduralized, automated and/or made more objective. In these ways, R&D can threaten the status of user as instructors (i.e., instructional technology might replace them or at least diminish their importance -- the "John Henry effect").

5. The use of low-cost, low-fidelity trainers, although able to provide effective training, can be interpreted by instructors as another sign that they are "less elite" than other occupational specialties in that their group has to "make do" with "inferior supplies".

6. Instructor time spent in a trainer can decrease instructor time with operational training equipment (e.g., aircraft). However, career advancement, as well as personal enjoyment, often seems to depend on use of operational (vs. simulated) equipment. Thus, R&D that seeks to reduce the inefficiencies of training with operational equipment can threaten both the enjoyment and career advancement of the user.

7. Although the principle of feedback is central to both motivational and learning theory, R&D personnel in training have been criticized for not providing knowledge of R&D results to the participating training organization. In a recent example, an operational squadron was less than

enthusiastic about starting a new study partly because they hadn't received even the final report of a study completed two years earlier.

8. There are predictable psychological responses to change which lead instructors (and others) to resist innovation. Such resistance is well documented (33) under a variety of conditions, including innovations in training and educational methods:

a. Basic security needs will be compromised in the face of uncertainty induced by the changes. For example, the instructor can feel unqualified to implement new procedures.

b. A second natural response to the innovation is that more effort will be necessary to implement the change than that required to continue older procedures.

c. It is also frequent for the implementing organizational unit to feel criticized in the face of the change. No amount of logical persuasion and discussions regarding the value of change can completely counteract the instructor's conclusion that current performance may not be adequate. Since there are few absolute standards of the value of his work, the work of the implementing instructor personnel is judged largely on the basis of relative standards, including R&D evaluations.

d. Finally, the members of the implementing organization will likely experience some degree of loss of freedom (or even perceived manipulation) by an outside agent. In discussing the personal response to managerial control systems, Cleland and King (9, pp. 330-331) have identified several common yet unintended consequences of control systems (as paraphrased from McGregor, 21). Managerial control and related restrictions on freedom initiated by R&D may yield: (1) failure to comply with the full requirements of the control system; (2) antagonism to the controls and to those who administer them; (3) unreliable performance information due to erroneous and/or misleading reporting; (4) necessity for close surveillance by managerial staff; and (5) high administrative costs due to the expense of surveillance.

Deficiencies in User Role Assignments. Inadequate liaison between R&D personnel and users also exists because of a lack of proper definition, acceptance and performance of social roles for various members of an R&D project. The social role literature, usually defines two kinds of role "stresses" -- role ambiguity and role conflict. Role ambiguity refers to a lack of clear definition of one's appropriate role behaviors; role conflict refers to two or more clearly defined roles in which simultaneous performance prevents either role holder from successfully fulfilling his responsibilities. A prevalent example of role conflict is between the R&D scientific role responsibility and the instructor's primary role to rapidly provide trained pilots, which very often requires training command resources completely devoted to the "urgency" of meeting the squadron training needs. To further aggravate the situation, many R&D efforts can provide only partial answers to training problems, which are not solved until several such answers are pieced together. The cooperation of users can become severely strained when it becomes clear that the slow, cautious, methodical, self-critical approach of the R&D project is not going to provide answers fast and sure enough to satisfy their current operational needs. Operational restrictions on experimental control can slow the R&D process by necessitating further R&D to answer questions about possible influences of uncontrolled variables.

A deficiency more serious than that of role conflict is role ambiguity. There is no basic conflict between users and R&D personnel in terms of their basic responsibilities for enhancing training effectiveness. There is a problem, and resultant stress for both parties, however, when roles are ambiguous, as currently exist for users working with R&D personnel. Clear roles defining expected liaison behaviors are absent.

There are at least two predominant kinds of response to role ambiguity. One may become "irresponsible" and give up trying to play any role at all. Or, an individual may try to assume all the behaviors that might fall under the jurisdiction of his usual organizational responsibilities. This latter response is fairly typical of pilot training in which instructors usually approach their job with a high sense of responsibility. However, role assignments are inappropriate when users attempt to evaluate technical research aspects of R&D efforts, such as research design and statistical analysis. When users begin taking on the role of R&D personnel, a third kind of role stress, which could be called "role overlap", develops. With role overlap, neither party in the relationship can feel responsible for successful role performance since there are multiple claims on "ownership" of the role behaviors. Like role ambiguity, role overlap can also lead to irresponsibility. If skilled R&D personnel are not given the opportunity by users to deal with the technical research issues, they are not "response-able"; if highly influential users do not have the necessary research expertise, they are not "able-to-respond".

There are several areas in which inappropriate role overlap currently exists:

1. Replication of a previous study (whereby the experimental conditions of an earlier experiment are essentially reproduced) often is viewed by users as "duplication of effort". Duplication of effort occurs and should be avoided, according to many users, where two or more R&D projects address the same general goals (e.g., optimization of the same training device). However, when the R&D objectives have critical implications for human lives, money, and mission success, multiple approaches to the same R&D objectives can be quite desirable and even imperative. Equally important, replication plays a critical scientific role in the R&D process in terms of defining the external validity or generalizability of previous findings across time, subjects, assumed irrelevant variations in experimental procedures, etc. In the case of truly independent replications, R&D findings be-

come extremely credible where similar conclusions are reached. Behavioral research is replete with experimental findings that cannot be replicated even under the best of conditions. Thus, replication needs to play a much greater role, especially in operational settings of minimal experimental control.

2. A relatively large sample size is considered by the user to be essential in order for any objective of the R&D project to be met. However, the size of an adequate experimental sample is a complex matter involving consideration of a number of design and statistical issues (e.g., the use of repeated measures, the error variance of the sample population, the extent to which experimental controls can be implemented), and the nature of the study objectives.

3. Operational users often want to consider the cost of the R&D as part of their evaluation of the project. This practice is inappropriate because R&D costs should be evaluated in a context of its contribution to technological information bases, as well as to the development of specific new products. Since, at best, users only have information related to the value of potential new products for their particular situation, user efforts to evaluate the general costs and benefits of the R&D are not completely meaningful.

4. The need for R&D is diminished in the view of users to the extent that they perceive their current training program as already successful. However, a major role activity of R&D scientists is to provide an independent assessment of organizational effectiveness. In addition, their responsbility is to help assure that a successful program is preserved over time through documentation and standardization of training procedures. Further, it is important to determine as precisely and accurately as possible what the criteria for training program success are, how well the training is in fact working, and what specific aspects of the training are contributing to or detracting from the level of success observed.

5. It is often expected by users that details of the research design for solving the R&D problem will be discussed very early in the project and often in the first kick-off meeting with users. This view conflicts with R&D requirements to delay specification of such details until appropriate rationale for such details can be obtained, which often involves the cooperation of the users who are requesting the details. It often happens that the R&D team is pressured into becoming too detailed too soon, with the result that the R&D design is quickly criticized as being inappropriate for the particular operational situation in question. Such criticisms are usually valid since a major contribution of users to R&D is to help determine an R&D design that is well suited to their particular situation. Thus, discussions at initial meetings between R&D personnel and users should include only the level of detail needed to evaluate the general R&D approach in terms of specific operational constraints such as current training schedule, instructor personnel and student throughput.

R&D managers have often been deficient in the application of participative management (PM) to capitalize on the user's expertise. PM could assist to more clearly define appropriate user roles (see below).

Deficiencies in Official Navy Organizational Policy and Structure. There are a number of constraints on acceptance which have little or nothing to do with individual motivation of the user or his social role interactions with R&D personnel. Direction from official policy at the training organization or even regional or national level of influence can restrict the successful introduction of R&D. An understanding of some of these policies can be extremely valuable because policy changes can help to overcome "Navy Policy" obstacles. Less directly, policy modifications also can aid in resolving the constraints discussed throughout this paper.

1. There is a prevalent and generally supported view in the Navy that R&D should be conducted with no interference with ongoing operational training. Semple (29), e.g., has specifically advocated a guest-host relationship in conducting training effectiveness evaluations with operational user hosts. A policy statement from the Chief of Naval Education and Training (CNET) subsequently formalized Semple's not-to-interfere-with-training concept. However, since most important R&D conducted in operational settings requires some such "interference", this conception often is counter-productive. Lacking a generally accepted definition of what interference means and how it applies to various R&D situations, this view can be taken literally and enforced by the user in cases where it should not be. A policy of non-interference also contributes to the impression that R&D is a low priority activity which is to be tolerated, if necessary, but is not to be given serious consideration by the user organization.

2. Current Navy policy requires frequent instructor rotation and training support personnel turnover. Thus, in the process of introducing an R&D project, one or more key personnel are almost always about to leave the organization. For these individuals there is no incentive to make a commitment to the project since any benefits resulting from the project probably will not occur until long after their rotation date. In addition, all the risks and uncertainty of change common to the initiation of any R&D project will be experienced if a commitment is made. Furthermore, frequent personnel rotations create problems when new users come to the project subsequent to its initiation. Efforts to indoctrinate users to the project need to be repeated each time a new member arrives. The new project members do not have the benefit of feeling that their efforts have influenced the determination of project goals or the methods used to achieve them. The issue of turnover is a crucial one in gaining initial acceptance as well as continuity of acceptance throughout the project.

3. The typical aviation training organization does not provide guidance for adequate instructor pilot (IP) training. Current instructor training policy is almost entirely on the job training (OJT) conducted very informally and sporadically as primary training schedules and other commitments permit. The training provided

to prospective instructors is not a basic but a collateral duty of the "qualified" instructor. As a consequence of inadequate instructor training to operate ATDs, R&D with ATDs is less likely to be accepted for at least three major reasons:

a. The new instructor is forced to develop his own unique training techniques used with the ATD. The emotional commitment to methods that one has developed himself is generally much stronger than those recommended or required by other people, such as R&D personnel (cf., 32). Thus, there is likely to be much greater resistance to a proposed change in training techniques than if the techniques were relatively standardized across instructors.

b. The lack of standardized instructor training and consequent diversity of opinion about what is important in training make it very difficult to achieve a cohesive user position in support of certain proposed changes in ATD training. In addition, the integration of new standardized procedures with instructors who previously have used highly heterogeneous training procedures is a problem because the relationship of the new procedures to existing ones needs to be examined on an individual instructor basis.

c. As device utilization methods pass informally from older to newer instructors, much of the original information is lost due to limitations in recall, oversimplification, etc. The natural oversimplification of the capabilities of ATDs over time helps explain the well documented fact of underutilization (e.g., using an OFT as a CPT) of a wide variety of Air Force and Navy ATDs. Thus, research projects which attempt to foster the use of the full capabilities of an ATD which has been passed on by several generations of instructors may meet with considerable resistance from current instructors.

4. With certain exceptions, such as the presence of Fleet Project Teams (FPTs), local training commands often do not have policy support for the personnel and resources required to accommodate an R&D effort. Some organizations are genuinely overloaded with existing operational training responsibilities.

<u>Inadequate Defense R&D Contracting Methods</u>. Government contracts involving operational training organizations tend to ignore the reality of the user acceptance problem until the contract work has begun. Scientific officers monitoring these contracts seldom require the contractor to develop a methodology for gaining acceptance. Nor is there a contractual requirement to document successful and unsuccessful acceptance methods. Consequently, there are no contractual provisions for the necessary time in the early part of the schedule to achieve acceptance milestones nor are there funds allowed to achieve and to document these milestones. Thus, each new R&D study is forced to "rush through" the acceptance problems by placing further pressure on the user. This pressure is applied without benefit of the lessons learned from previous studies that have experienced similar difficulties.

<u>Inadequate Integration of the User Into The Trainer System Acquisition Process: A Lack of Participative Management</u>. The formal structure of the Weapon System Acquisition Process, including training system development, requires user input and participation at several points in the process of ATD acquisition. Caro et al. (7) have found that participation of Air Force users during ATD design as well as during initial ATD effectiveness evaluation in the training environment, significantly improves attitudes toward the ATD. Mecherikoff and Mackie (22) found that a lack of such participation among Navy personnel created a strong negative attitude of "not invented here." There generally has been little systematic application of participative management (PM) techniques to the entire process of trainer acquisition and subsequent evaluation, including initial effectiveness evaluations and later ATD training optimization studies. PM has not been applied due largely to the three limitations indicated below:

1. Lack of recognition of the value of PM as a general tool for gaining acceptance of change.

2. Lack of operational definitions as to <u>how</u> PM should be implemented during a specific proposed change in training methods.

3. Lack of formal documentation of successful applications of PM to specific military training organizations.

A successful introduction of an R&D study will be more likely if it is made clear to users as soon as possible that a participative approach is desired. There is considerable empirical support for the value of PM as a general tool for introducing organizational change (16). In addition to the empirical basis for using PM, there are a number of more "intuitive/logical" reasons for using PM:

1. PM makes use of subject matter experts (SMEs) from the training command to provide necessary information to R&D personnel. Information regarding current training system practices and resources as well as suggestions for alternative R&D approaches and methods are especially critical in the complex system in which aerospace training takes place.

2. PM allows the SME to learn that he is valuable. A natural response to change, described earlier, is a feeling that one is being criticized for inadequacies. With PM used to introduce change, the SME learns that he is not being replaced. Certain behavioral practices of training may be replaced, however. To the extent that SMEs feel that they are being evaluated, PM encourages them to participate in determining the basis on which their efforts can be judged (16).

3. PM reduces the natural resistance due to uncertainty of an unknown change and its consequences.

4. PM reduces the natural resistance due

to the perceived loss of freedom initially attributed to presence of R&D personnel. The PM approach encourages full expression of dissenting opinions and is consistent with the democratic decision-making ideals generally held by this country.

5. PM allows the user to understand the likely level of complexity of the proposed change. If the user does not grasp how everything ties together in the R&D plan, he is likely to make changes (especially an upgrading of requirements) during the study without evaluation of the probable impact of changes on technical performance, schedule, or cost risks (10).

6. PM provides a context for group activity which can satisfy certain social needs such as affiliation.

7. PM identifies personal sources of necessary support for the change who were not initially part of the group participation.

8. PM informs "outsiders" of the informal rules of the organization which can complement the formal support of change.

9. As a result of a number of the foregoing advantages of PM, PM increases the organizational members' commitment to the change goals and objectives established. This consequence of PM is the single most valuable benefit of PM and also has been empirically documented (16). Participating in the development of a change effort gives one the experience of "owning" the change and responsibility for supporting its implementation. Thus, the implemented change is much more likely to be long-lasting, perhaps even eventually institutionalized into the training organization.

The value of PM as a general tool for gaining acceptance of change is becoming more widely acknowledged. However, there are few operational definitions of how to implement PM into operational military systems. However, there is at least one significant, but preliminary attempt to proceduralize PM into the evaluation of complex aviation systems throughout the weapon acquisition process. Butterbaugh, Moss, Sexton, and Kearns (5) have developed an acquisition process model for the Air Force that focuses extensively on user input evaluations throughout the process.

It should not be assumed that PM is a panacea for all organizational change goals. The success of PM over the alternative change strategy of directive management (DM) depends on the results of organizational diagnosis by the change advocates. This overall diagnosis would not only tell the R&D personnel whether change should be attempted at all, but also which change strategy would be more likely to be successful with the particular organization involved. The prime factor determining the relative efficacy of PM and DM, according to research in situational leadership theory (16), is the level of "task-relevant maturity" diagnosed in the group members. People with high task maturity are "achievement-oriented, seek responsibility, and have a degree of knowledge and experience that may be useful in developing new ways of operating ... A directive change style is inconsistent with their perceptions of themselves as mature, responsible, self-motivated people who should be consulted throughout the change process". (p. 283). This description of high maturity seems to fit very closely the operational users of primary interest in this report - namely pilots. An earlier section of this report pointed out that the typical instructor pilot has an intense responsibility to his operational tasks. Such responsibility, combined with the usual high degree of task-relevant expertise among pilots, is an extremely valuable asset in improving training systems.

<u>Other-Then-Rational User Responses to R&D Studies In Training</u>. Different methods of introducing R&D into operational military training organizations can be used. At a heuristic level, there are three general methods used to gain acceptance of R&D. The user may be told that he: (1) <u>shall do it</u> (power of higher authority); or that he <u>(2) can do it</u> (power of persuasion based on rational/logical arguments supporting the technical feasibility of a proposed change); or that he (3) <u>wants to do it</u> (power based on the user's own emotional/motivational/value system which is consistent with or satisfied by the proposed R&D study). Ideally, all three reasons exist to support acceptance. Seldom, however, is there clear and powerful "shall do" authority for initiating specific R&D studies; R&D personnel are normally staff officers without command authority.

The typically used method involves rational/logical appeals to the operational users' intellect based on the training value of the proposed R&D effort. This "rationalistic bias" of R&D specialists is also found in non-military organizational change efforts (33) and assumes that change requires no more than an exchange of technical knowledge. One of the major constraints on gaining user acceptance, however, is that acceptance of change is naturally influenced by emotional factors that are not strictly "rational" in nature. In the Navy maintenance training area, e.g., there exist severe acceptance problems of training devices although these devices were designed and validated according to principles of modularity, self-pacing, criterion-referencing, etc. Even where technical arguments are clearly made, they are not always sufficient. It is argued, therefore, that the successful R&D scientist must have skills which allow him to anticipate and deal with these "other-than-rational" user responses which can lead to lack of acceptance of a proposed study.

These responses to the introduction of an R&D study occur in many forms, but they can be classified in at least three basic ways. Some examples from naval aviation, as observed by various scientific officers and contractors working with the Naval Training Equipment Center is provided for each of these classifications. (A follow-on paper will attempt to describe these same kinds of responses by scientific officers, as observed by operational users).

1. <u>Emotional resistance based on the particular operational organization's situation.</u> Commonly heard statements by users include:

a. "Our situation is unique - training results found elsewhere don't apply to us".

b. "Our situation is too complex to study".

c. "Even if your proposed study could improve our training for now, our situation will change".

2. Emotional resistance based on the lack of credibility of the R&D specialist.

a. "You can't evaluate the flight simulator if you haven't flown the actual aircraft".

More generally, this response implies that operational experience is a prerequisite for credibility as an evaluator. This view would be perfectly rational if the evaluator's responsibility was to improve or practice his skills as, for example, a pilot. Some users even take the extreme view that evaluators must be equally proficient at operating the actual equipment. Obviously, however, the user is the operational expert and it would not be cost-effective to require of R&D specialists more than a minimal degree of operational experience. Logically, the R&D scientist could also insist that the user be as skilled as he at performing R&D. Of course, this logical alternative to requiring the R&D specialist to be operationally experienced is seldom stated since it is recognized that there are necessary and complementary forms of expertise represented by both operational and R&D personnel. If the R&D specialist's skills overlapped completely with those of the user he would have nothing unique to contribute to improving training effectiveness.

Although it would be difficult to insist that operational experience is detrimental to one's effectiveness as an evaluator, it is not always possible to show that such experience improves effectiveness. It has long been thought in clinical psychology, e.g., that direct experience with a client's symptoms would facilitate a counselor's effectiveness. However, specific research (30) with alcoholics treated by previous alcoholic counselors showed that success rates were no higher than for those treated by "non-empathetic" counselors. It is probably true that such empathy would increase the chance of the client accepting a treatment program in the same sense that the study proposed by a credible R&D evaluator would be accepted. This initial acceptance, in both cases, is based more on emotional grounds than on grounds of potential effectiveness, however. The user can easily identify with and accept operational task experience as grounds for credibility. The R&D specialist's expertise in such tasks as problem definition, development of methodological procedures, statistical analysis, oral and written communication of results, etc., none of which are dependent on operational experience, is much more difficult for the user to appreciate.

3. Emotional resistance based on attitudes towards ATDs undergoing evaluation.

a. "The TDs (Training Device Maintenance Personnel) fly the simulator better than real pilots".

With certain carrier landing trainers, users sometimes use TDs to provide ATD demonstrations to visitors because "They can catch the #3 target wire every time". Although there is nothing inherently irrational in this statement (it is true), the underlying attitude is negative towards the ATD since it is implied that the simulator teaches skills not required by an experienced carrier pilot. The illogic of this attitude is based on acceptance of the conclusion that TDs would not be able to land on a real carrier even if they were proficient in the simulator. However, TDs are not given the opportunity to actually attempt carrier landings and thus there is no empirical basis for accepting this conclusion. Even if the TD could not land on the real carrier, presumably because the landing trainer does not teach all the skills required for landing success, a significant portion of the required skills learned by the TD would transfer to the actual landing task.

b. "If a flight simulator doesn't feel right, it has no training value".

This response aptly illustrates a general phenomenon, observed by Mackie et al. (20). They found that users often feel that unless the ATD is perfect in all respects, its use for any reason is regarded as a waste of time. The device is then likely to be regarded as a "toy" or as a "pinball machine".

Deficiencies in Training Device Design. The primary systematic approach to acceptance has been identification of deficiencies in ATD design (7, 20). This approach is fundamental to the solution of acceptance problems because the deficiencies can be fairly easily isolated and future ATD design presumably modified to correct them. Deficiencies in device design is one of the most severe constraints on the acceptance of R&D studies introduced to training organizations. However, it is in the ATD design area that the scientific approach can be most easily applied to predict and control the level of acceptance of ATDs. Changing the machine (i.e., the ATD) to fit the man (i.e., the ATD instructor and student) may be much easier than attempting to change the man (user) who does not accept the machine.

The acceptability factors in ATD design fall into two general classes: (1) hardware/firmware features, and (2) software/courseware features. This first class essentially includes a variety of physical fidelity factors relating to the student work station (and the physical layout of the instructor work station). It would include, e.g., the presence and appropriate positioning (absolute and relative) of necessary controls and information displays inside the cockpit. The second class includes both physical fidelity factors created by computer simulation (e.g., visual and/or motion effects) and various instructional features designed into the software.

## AN INITIAL MODEL OF THE PROCESS OF ACCEPTANCE OF R&D - INDUCED CHANGE

Figure 1 portrays a preliminary model of acceptance. The model identifies these stages of innovation as formulated by K. Lewin (19) and the four related changes conceptualized by Rogers and Rogers (27). The first stage for Lewin is called "unfreezing" which implies that change, e.g., introduction of an R&D study, can occur only after the individual or organization is ready for it. Listed under this stage are several kinds of factors or "forces" (discussed in this paper) that would decrease the risk of transitioning to the second stage, termed "changing", wherein the changes would actually be made.

Separate from the forces that would support change is the original recognized need or requirement for change. This recognition, of a discrepancy between available training technology and current capabilities, is the first stage of innovation for Rogers and Rogers. Both a recognized need for change and the presence of forces supporting the change are necessary to transition to the second stage in which changes are trial tested, e.g., in the form of an R&D study. The last stage for both theorists is "refreezing" (19) or institutionalization of the change (27), e.g., integration of R&D results into ongoing training methods to improve organizational effectiveness.

Five levels of change, ranging from a change in individual knowledge to a change institutionalized in organizational policy, adapted from Hersey and Blanchard (16), is also presented in Figure 1. These levels of change correspond roughly with the stages of the innovation process. Knowledge (e.g., of the latest technology), the lowest level of R&D-induced change, is the basis for Rogers and Rogers' first stage in which

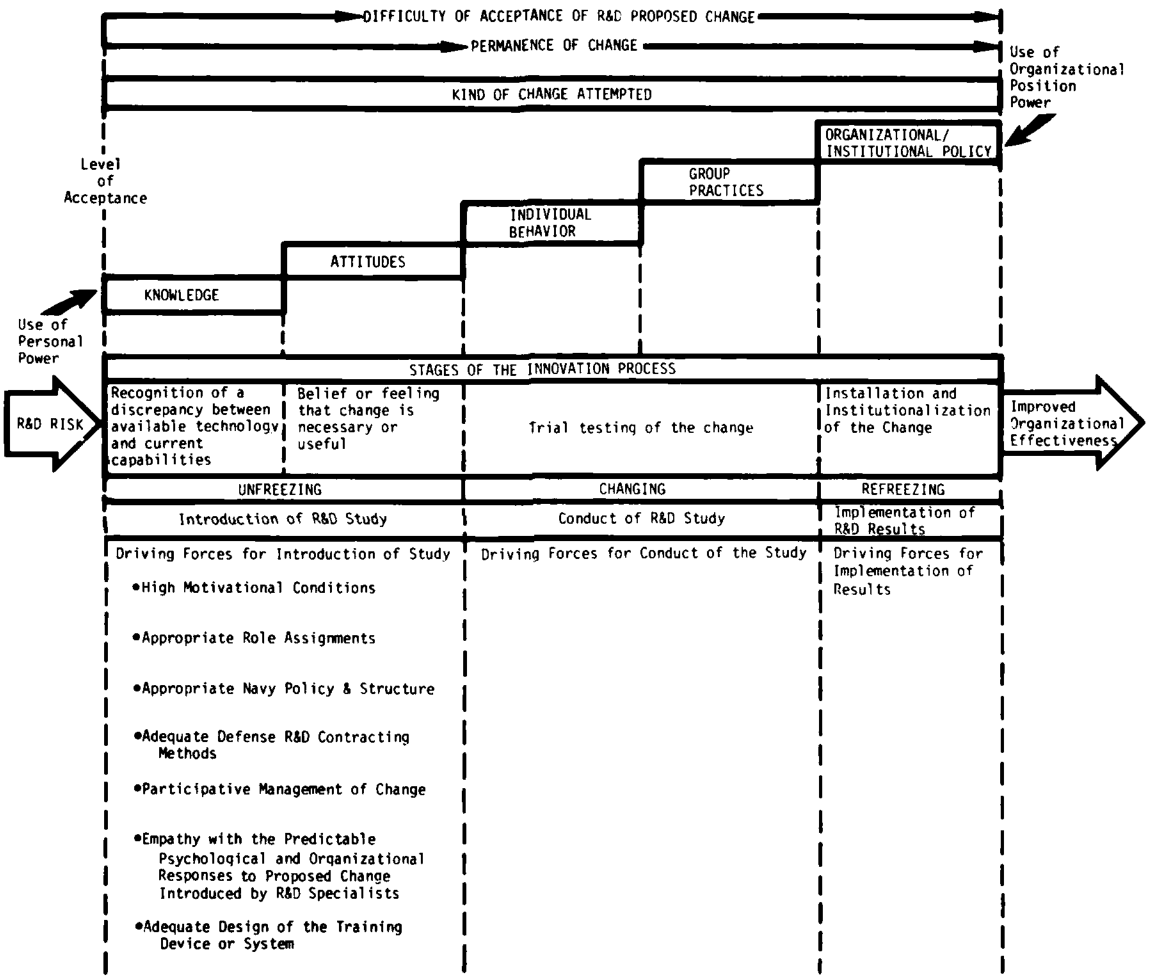


FIGURE 1. A preliminary model of the acceptance process. Indicated are the stages of change and a listing of factors supporting the initial stage of introducing an R&D study (as emphasized in this paper). The use of personal power typical of R&D specialists vs. the organizational power present in the training command structure is shown applied to different levels of attempted change. The model includes elements from Hersey & Blanchard (16), Lewin (19), & Rogers & Rogers (27).

the user recognizes the existence of improved technology. Their second stage, which is the belief or feeling that change is necessary or useful, corresponds to the next highest level of change in which attitudes are supportive of the change proposed by the R&D specialist. This motivation to change is the third necessary ingredient, along with recognition of a need and the presence of driving forces supporting change, for successful initiation of R&D.

The present paper has focused on acceptance of the introduction of an R&D study. The stages of innovation, however, also include individual and/or group behavioral commitments in order to trial test the changes successfully introduced by the R&D study. These commitments represent more advanced levels of acceptance of change because they include all the lower level knowledge and attitude changes and are therefore more difficult to achieve. The highest level of acceptance is change translated into institutional policy such that it is no longer recognized as a change. The forces supporting changes at these higher levels of acceptance are probably similar to those driving change during the first stage of innovation and will be presented in other papers in this area.

The model also indicates that the "shall do" kind of influence based on the power of positional authority (13) comes from the top organizational levels such as the commanding officer (CO) whereas personal power starts at the bottom levels. R&D personnel are ultimately trying to make changes at a relatively high level (i.e., at the group and/or organizational level). If change is achieved at these relatively high levels, the change is more permanent and may even become institutionalized. However, this task is extremely difficult since R&D personnel are usually limited to personal power. Whereas a CO could initiate an immediate and dramatic organizational change through the power of his position, the R&D specialist must begin his goal of organizational change by first changing knowledge of, and attitude toward, the proposed change. The concept of personal power involves the power of technical content expertise in interpersonal relations. As suggested elsewhere, most human factors R&D personnel have not fully developed their personal power of influence in terms of interpersonal relations based on an understanding of the operational user's emotional/motivational/value system of acceptance.

## ISSUES IN USER ACCEPTANCE

The general constraints on user acceptance appear to be a useful means for classifying approaches to acceptance problems. However, there are a number of specific issues regarding acceptance which remain to be addressed. Two of the more critical and controversial issues introduced in this paper are: (1) how are subjective user reports best used in the measurement of acceptance; (2) to what extent should maximal physical fidelity be the goal of training system design?

These two issues are related in that user opinion often seems to take the stance that higher device fidelity is always better. As indicated earlier, physical fidelity seems to be the single most important determinant of user acceptability. In contrast, many R&D efforts lead to the conclusion that deviations from maximal physical fidelity are possible and even desirable in the interest of cost-effective training. These differences in orientation are reflected by the use of the concepts, "simulator" and "trainer". The former term has come into vogue with unfortunate consequences on training efficiency, since it implies that training devices are superior only when they closely resemble operational conditions. This implication is strengthened by the challenge from users that training designers do not yet know enough about training to risk deviations from maximum possible levels of simulation fidelity. However, enough is known now to deviate significantly from the "simulation" criteria of acceptability and to place emphasis on the device's "trainer" features (i.e., features that facilitate positive transfer to operational settings).

Discussions of the processes by which training device fidelity (and consequently costs) can be reduced and learning can be maintained or even increased are presented in a variety of sources (e.g., 4, 7, 18). Two separate R&D demonstrations of these processes are underway at NAVTRAEQUIPCEN. A low-cost, low-fidelity cockpit procedures trainer (CPT) for the SH-3H aircraft has been developed and partially evaluated and early results indicate essentially equivalent training at about 17 percent of the cost ($310,000 vs. $1,800,000) of an existing more conventional, higher fidelity CPT for the same aircraft. Similar approaches are being taken and similar results are expected with a low-cost part task trainer for the EA-3B aircraft.

Further evidence corroborates the notion that high fidelity is not essential nor even necessarily desirable for effective learning (18, 31). For example, up to 50 percent savings in flight hours has been obtained from practice on low fidelity flight trainers. Also, fidelity requirements are found to depend on factors such as the amount of transfer of training required, the prior experience of the student, and strategies of instruction. Numerous studies have demonstrated that the training of aircraft piloting can be effective where patterns of stick forces, rather than the absolute amount of force or displacement of stick movement, correspond with operational conditions. Such deviations from high fidelity may be highly justified on a cost-effective basis, but rejected by users based on fidelity considerations.

Traditional practice has been and to a large degree still is to buy user acceptance by increasing the fidelity of simulation. A topical question regarding this practice is: how much can we afford to spend on device features for the sole sake of user acceptance? A trend appears to be at hand where such expenditures will be minimized and more low cost trainers will be replacing high cost simulators.

The issue remains, however, that if R&D indicates the desirability of lower cost/fidelity trainers, how do we deal with subjective impressions of user personnel which are often in conflict with their use? These subjective reports are the traditional and most common form of acceptance. One approach to resolving this dilemma is to empirically ascertain the ability of users to subjectively assess the training value of devices. This can be done in part by determining the reliability of user opinion (i.e., agreement among users) regarding both the acceptability and training value of particular device features (17). According to Sammet (28), there is seldom a cohesive or unitary operational user when operational needs are specified by the user. The same lack of consistency may be documented for user evaluations of ATDs. However, if user opinion is reliable, further R&D would be needed to document the relationships between user assessments of the training value of device features and actual student learning with these features. In this way, an empirical basis for the utilization of user evaluations could be established. There is evidence at NAVTRAEQUIPCEN, e.g., that user judgments of the necessity of motion in flight simulators are related to their actual performance in these devices for some types of motion systems but are not for others (26).

## CONCLUSIONS

The user acceptance area appears to be in a condition similar to the instructional development field prior to the advent of the Instructional Systems Development (ISD) era. That is, no systematic procedures are available and little sharing of information occurs regarding naval user acceptance problems and their solutions. Further, very little science has developed in the area and, at best, practices represent a very under-developed art. As a result, one must depend mainly on his own personal experiences and mistakes and his own independent actions to solve the problems.

Given the obvious cost benefits and improved readiness resulting from increased acceptance, it is surprising that so little empirical work has been done to identify a set of acceptability factors and factor priorities for different classes of trainers. Similarly almost no guidance exists as to how to successfully introduce R&D studies into training organizations. It is hoped that this paper has adequately stated the severity and scope of the acceptance problem. A second paper is planned to identify solutions which will involve overcoming the system constraints on acceptance described herein and to continue development of the model of the acceptance process.

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*An intent of this paper is to stimulate discussion of different points of view in the acceptance area. This report represents the opinions of the authors and should not be taken as official Navy policy.

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CONSIDERING PEOPLE AT THE POINT
OF "MENS" MAKES THE DIFFERENCE

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## ABSTRACT

The classical consideration of people requirements "after the fact" in weapons systems or simulator design instead of during concept definition is posing ever increasing threats to the survival of new programs. Systems in a military environment composed of manpower shortages and reduced skill levels are being fielded with an inadequate provision for tailoring equipment/software which minimize skill requirements or ease of performance training. People are at the heart of any system. The Personnel Subsystem is one of the major system components which must be considered at the point of defining the Mission Element Needs Statement (MENS). Hardware and software are designed to extend the reach of the available manpower pool to meet a mission need; therefore, OMB A109 clearly requires that the definition of the personnel subsystem, including the training and training equipment requirements to develop the personnel, must commence at system concept formulation and continue through subsequent development of integrated logistic support.

## INTRODUCTION

Considering people at the point of "MENS" makes the difference. As we all know, personnel constitute a key part of all systems. The objective of this presentation is to discuss the importance of considering personnel at the earliest possible point in a system acquisition process for major systems, definition and outline of the MENS, and how and why personnel are key to a viable MENS.

Office of Management and Budget (OMB) Circular No. A109 establishes the policies to be followed by executive branch agencies in the acquisition of major systems. The circular covers procurement of all major systems by the government. In this presentation, only DoD system acqusitions will be covered. The acquisition process is cued by the mission area analysis. See Figure 1 - Acqusition Process. The Secretary of Defense in conjunction with the DoD Components has established mission areas essential to accomplish the Defense mission. Each DoD Component Head has established a set of procedures to analyze their assigned mission responsibilities. This continuing analysis identifies mission elements for which existing or projected capability is deficient in meeting the essential mission needs and areas where existing capabilities could be enhanced.

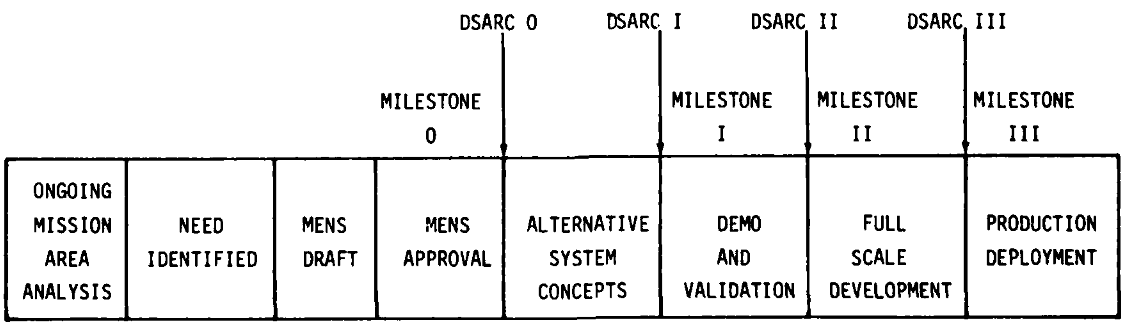


Figure 1 - Acquisition Process

When the Component Head identifies a deficiency, a description of the mission need is submitted to the Secretary of Defense. Once this Mission Element Need Statement (MENS) is approved by the Secretary of Defense the acquisition cycle begins. This point in the acquisition cycle is "Milestone 0". This portion of the acquisition cycle is normally unfunded but is key to the acquisition process.

Recent track records indicate that only approximately 25% of MENS submitted are approved. One of the major rejection criteria has been that they have been too constraining. The intent of the MENS is to identify a need not its solution. The mission need may best be satisfied by a change in doctrine, by deploying additional personnel or equipment, by training, by trainers/simulators, by modification of existing equipment, or by a new major system acquisition; however, the selection of an alternative solution is the objective of the next phase of the cycle--not the MENS. The MENS must state only the need, the current capability to satisfy that need, and the constraints. I will return to the MENS and the importance of considering personnel a little later.

First, I would like to proceed with an overview of the acquisition cycle in order to demonstrate the relationship of the MENS to the total cycle.

ACQUISITION CYCLE

The next step in the process is to explore and develop systematically and progressively the alternative system concepts which satisfy the approved need. Once this is accomplished and it is felt that selected alternatives should be demonstrated, the DoD Component Head requests approval to proceed with the demonstration and validation of the alternatives. The request is documented in a set of recommendations called a Decision Coordination Paper (DCP). The paper is reviewed by the Defense System Acqusition Review Council (DSARC) and the (Service) System Acquisition Review Council ((S)SARC) before the Secretary of Defense makes a decision. At this point, it should be noted that MRA&L (Office of the Assistant Secretary of Defense - Manpower, Reserve Affairs and Logsitics) now has a seat on DSARC. This assures that personnel will be a key part of the total process. From this point on assuming appropriate approvals, the system goes thru Milestone II - Full Scale Engineering Development and Milestone III - Production and Deployment. This completes the acquisition cycle. Let us now go back to the MENS phase and further explore the importance of personnel in the concept definition of a system.

ASSUMPTIONS OF RELATIONSHIPS

Some assumptions will be made concerning the human's relationship to the system.

1. There is a relationship between the efficiency with which people operate within a system and the total effectiveness of the system.
2. The characteristics of the system and the hardware within the system influence how men operate within the system.
3. It is cheaper and easier to adapt equipment/systems to human capabilities than it is to modify human capabilities to system requirements.

This last assumption requires some explanation. Prior to World War II, personnel played only a small part in the total system. A weapon system consisted of a fairly simple set of hardware - - operated and maintained by a very inexpensive, motivated labor force. Today's weapon system consists of ever-increasing complex hardware/software sub-systems operated and maintained by an expensive, sometimes unmotivated labor force with limited prerequisites.

MENS CONTENT

With these assumptions in mind, let's explore the requirements of the MENS. An outline of the elements of a MENS can be seen in Table 1 - MENS OUTLINE.

Table 1 MENS OUTLINE

1. Mission
2. Threat or Basis of Need
3. Existing and planned capabilities to accomplish the mission element need
4. Assessment
5. Constraints
6. Impact of staying with present capability
7. Resources required to meet Milestone I

The first element of the MENS is a statement about the mission itself, what is the mission area and specific subset(s) of the mission area.

The second element is a short statement on the need,in the case of a weapon system this is usually in the form of a threat. Quantification of this threat or need in numbers and capability, whenever possible, is described.

The third element is a brief summary of the existing and planned DoD and allied capability to accomplish the mission.

The fourth element is an assessment of the need expressed in one or more of the following terms:

1. Deficiency in the existing capability in areas of manpower, performance, cost effectiveness, or time period of the existing capability. As can be seen, people can induce the deficiency.
2. Technological opportunity
3. Force size

4. Physical obsolescense of equipment
5. Cost savings opportunity, life cycle cost potential for savings
6. Vulnerability of existing systems

The fifth element is the constraints placed upon the need or the solutions. These include:

1. Affordability in relationship to the overall Service budget.
2. Relative priority within the mission area. - It might be mentioned here that for every program the acquisition cycle requires a yearly assessment of the relative priority. This is what causes a fluctuating budget over the span of a program. It's priority in relation to other programs on a yearly basis dictates it's yearly budget.
3. Logistics and manpower consideration. Here again people come into play. A very key element of a system is the constraint put on the system by it's personnel and logistics support.
4. Standardization/commonality with NATO as well as among the other Services.
5. The timing of the need.

The sixth element is the impact of staying with the present capability. This includes such things as ability to meet the threat or need, impact on combat effectiveness, and the cost of product improvements to the current system.

The seventh element is the identification of resources and schedule to meet Milestone I.

As can be seen, inputs concerning personnel are required in several elements of the MENS. Specifically, personnel are or can be involved as the source of a deficiency or need, or can constitute a constraint to the solution of the need.

A little later on in the presentation I will discuss an actual MENS and give examples of how some of these elements, especially those relating to personnel were documented.

REQUIREMENT FOR FRONT-END PERSONNEL ANALYSIS

The MENS must express needs and program objectives in mission terms and not equipment terms or solutions. Innovation and competition in creating, exploring, and developing alternative system design concepts must be emphasized.

Again these initial activities must allow for competitive exploration. As stated by CDR Paul R. Chatelier, USN, the systems of the future must be analyzed and supported by a detailed front-end analysis. Key issues that must be addressed by DoD Component Heads are:

- o The military force must become more effective with fewer personnel
- o Increased competition for defense funds between weapons and manpower
- o Personnel must become more efficient and productive
- o Cost effectiveness
- o Reduced funds, fuel, and ammunition for military operations and readiness exercises

The DoD community has initiated three service efforts which focus on front-end analysis. The efforts include the Air Force Logistics Composite Model (used primarily for maintenance manpower modeling), the Army's Personnel Affordability program, and, of particular interest, the Navy's HARDMAN program. HARDMAN (Military Manpower versus Hardware Procurement) is being designed to identify manpower, personnel, and training constraints as early as Milestone 0.

To date, there has been little motivation for program managers to take into consideration the life cycle impact of manpower on the system. The manpower, training, and training equipment considerations were coming too late in the acquisition cycle to influence hardware and software planning. HARDMAN takes personnel and training into consideration at Milestone 0 as alternatives during the Milestone I tradeoff analysis.

As I mentioned earlier, an actual program used as an example would be of some help in pulling some of these ideas together. The Navy's VTXTS program is an excellent example of a major system that is in the acquisition cycle and has an approved MENS. The VTXTS program also used HARDMAN to analyze the personnel requirements for the VTX aircraft. Becuase of this, manpower data was available for Milestone I trade-off evaluation - valid trade-offs could be made.

The Undergraduate Jet Flight Training System (VTXTS) is a multi-faceted training system which will be used in the intermediate and advanced phases of the Naval Flight Training Program to train pilots in the operation of jet aircraft. The VTXTS is to be developed as an integrated system of four mutually supportive major elements. These four elements are: academics, simulators, aircraft and training management system.

Let's now go thru the VTXTS MENS to gain a better understanding of the elements of a MENS and how they relate to personnel (see Table 2 - VTXTS MENS OUTLINE).

TABLE 2 VTXTS MENS OUTLINE

1. Mission
2. Basis of Need
3. Existing and Planned Capabilities to Accomplish this Mission
4. Assessment
5. Constraints
6. Program Plan to Identify, Explore and Evaluate Alternative Training Concepts

Some highlights from the MENS are: Under Mission "The overall mission area encompasses the continuing requirement to provide undergraduate pilot training. . . A need exists to extend or provide an optimized replacement for the present training system to meet future pilot production requirements." For the VTXTS program it can be seen that the mission itself is people oriented.

The next element is the Basis of Need. Again we can see a people influence. "The training of sufficient numbers of jet pilots is vital."

The third element is that of Existing and Planned Capability to Accomplish the Mission and it is broken down as follows:

A. Existing System Capability - here a short description of the current Navy undergraduate pilot training system was given.
B. DoD and Allied Capability - in this area it was stated that other sources do not satisfy the requirements.
C. Agencies and Components Involved - The U.S. Navy and Marine Corps and possibly NATO and the U.S. Air Force

In the area of Assessment the VTXTS had several items:

The first item consisted of a short description of the Training System Concept Requirements.

The second item identified deficiencies in the existing capability and of particular interest the statement "The existing Navy flight training system is becoming increasingly expensive to operate and maintain. Escalating personnel, material and fuel costs are driving ever higher student costs-to-train." It was also mentioned that the hardware was becoming obsolete but this did not receive as much attention as the personnel problem.

The last item to be assessed was the Opportunity for Cost Savings. Here it was discussed that a wide range of options would be evaluated to seek an integrated system taking full advantage of state-of-the-art simulation, and trainers including the Flight Vehicle.

The next major area to be covered was the Constraints to the System. The constraints included carrier operability, cost, timing for IOC, NATO Standardization and Interoperability and finally the constraints of manpower, personnel and training. "Design proposals for the system will include an assessment of life cycle costs and those potential life cycle cost tradeoffs between hardware capability and available manpower and logistic support. The basic manning concept for the flight training system is intended to influence system design to achieve the most cost and training effective military, civilian and contractor manpower mix."

The next major area addressed the "Impact of Staying with the Present System." The basic statement here was that the mission needs cannot be met with the existing system.

The last area was the Program Plan for Alternative Training Concepts. This covered the overall plan, the analysis effort, the assignment of a program manager and finally projected Milestones.

As you can see, VTXTS is an example of best case or worst case, depending on how you look at it, of a people oriented MENS. Since personnel and training were a part of the mission, the need, the deficiency, and the solution this was not exactly your typical MENS. It does however provide some food for thought on how people should be a part of any MENS.

Let's examine another key factor in determining why personnel must be taken into consideration in mission needs. The personnel available today in the military work force is significantly different in quantity and ability than it was when most of our current systems started into the acquisition process. What constituted the weapon system capable of fulfilling a mission then might no longer exist. The design of any system ultimately must include people - - either as operators or as maintainers. If the people available now as part of the system are not the same as those projected as being available during system design, there is a probability the system will not meet the total mission element needs. If the prerequisite tools expected of the human, e.g. reading level, motivation, electronic/mechanical aptitude, are not available in the quanity of people required, then a deficiency exists. In this case, the mission element need is expressed and assessed as a deficiency in the force available for the system. Trainers, part task trainers, and generic skills/competency trainers can help fulfill the need.

The preceding example depicted how people can be expressed in a MENS as an assessment of a deficiency. People must always constitute a constraint -- if it is accepted that the Personnel Subsystem constitutes a major component of a system. The availability and quality of a major subsystem must constitute a constraint. Again, it shoud be emphasized that in the past, the human was only a small part of the total system. A current system is considered to be composed of a Hardware Subsystem, a Software Subsystem, and a Human or Personnel Subsystem, see Figure 2 - A TOTAL SYSTEM. Any system may be composed of any or all subsystems, or a mixture of subsystems in any ratio. Looking at the pie-diagram on the left, we can remember when people-costs (labor-costs) were given only incidental consideration in comparison with the investment of new hardware. A couple of things have occurred by this point in time: 1.) Labor-costs have grown at a phenomenal rate relative to the cost of machines. This however is just the tip of the iceberg for the military. If one compares military pay to civilian pay for example:

- o Civilian starting salaries are 50% over 2nd LT's
- o Enlisted average salary is $9,900
  - o Staff Sgt with 10 years = Washington D.C. Unemployment
  - o 30% Below Minimum Wage

We must assume that the military pay rate will increase at an even greater rate, and that this increase will cause the people-costs for a system to be even more significant.

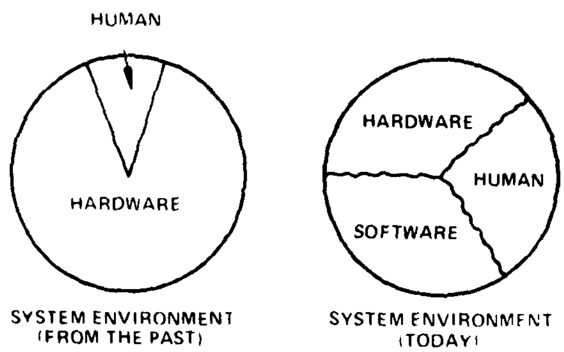


**Figure 2 A TOTAL SYSTEM**

2.) Computer power has vastly extended the leverage of man over machine and his environment. The pie diagram on the right better describes the system considerations of today. The system conceptualist, in synthesizing the alternative ways to meet the operational requirements, has potentially infinite options in allocating functions among the three subsystems.

People - - not dollars - - are going to be the ultimate limiting resource of future systems. This is obvious from at least two factors: 1.) the cost of people constitutes over half of the DoD budget, and the percentage is growing each year. 2.) Seventy percent of the decisions that affect life cycle cost are made by DSARC I.

## *CONCLUSION*

In conclusion, one must consider the cost, quality, and availability of the projected labor pool as part of the MENS preparation effort. The life cycle cost and viability of the threat-responsive system can be significantly impacted. This will force the requirement for trade-offs between 1.) the man, hardware,and software subsystems and 2.) and part-task or part-mission trainers and large full mission simulators which minimize the cost of procuring and supporting the total trainer package. It will also ensure greater concurrency between the configuration of the weapon system and that of the trainer suite.

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ABSTRACT

This article deals with the "buying-in" syndrome. Buying-in describes the contractor's actions in trying to win a contract award. In short, the government sets a trap for itself. Then the contractor bids below the actual costs in anticipation of being awarded a sole-source contract where losses are recovered. Government funding characteristics even encourage this action.

# BUYING IN SYNDROME

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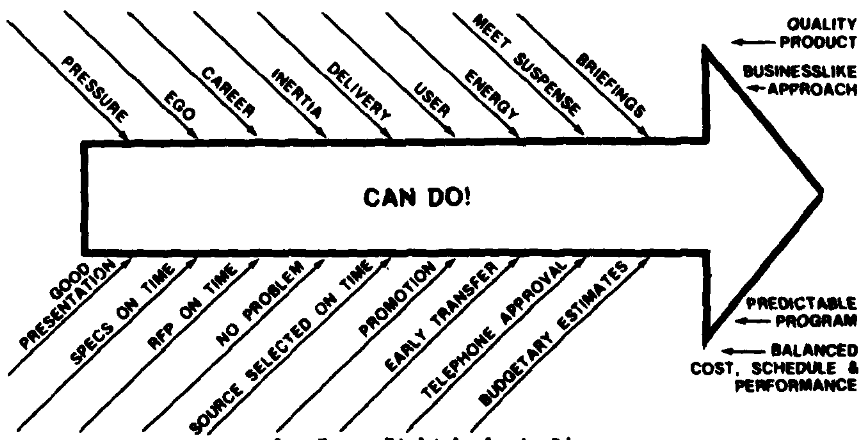
## INTRODUCTION

From one perspective, three distinct elements integrate to produce what we call the buying-in syndrome. First the government sets a trap for itself. Second the contract costs reported to the government soar, especially on follow-on contracts. Third, government funding cycles and obligation policies encourage contractor activities that aggravate the situation. This paper deals with the segments separately, with the first segment establishing the framework for integrating the other two. "Buying-in" is a term that has been bandied about in the acquisition business for as long as I can remember. Some government officials see buying-in as a sinister plot by contractors to secure a government contract under false pretenses. Some contractors see buying-in as bidding in the fashion that has become standard in the face of unachieveable government technical and schedule requirements. Another view is that company design, development and production techniques are so efficient that if enough units are ordered, the contractor will pay the government to take the last few units.

Simulator SPO data indicates a sort of pattern of activities that comprise a situation that becomes tagged as a buy-in. The situation consists of contractor bids that are nearly equ. to the government budget, with schedules equal to the government schedule. Best and Final Offers when received are significantly lower than the initial bid. Very shortly after contract award an over target condition develops, followed by anticipated schedule slips. The end result for the SPO Director is an overrun contract, late delivery and a short [illegible] of private audiences with the Commander. The situation doesn't start with the contractors' bids. The bids simply serve to spring the trap that the government has already set for itself.

Our trap is constructed by digging a hole for ourselves, making a camouflage cover for it, and then lining it with sharp stakes so that when we fall in we get hurt. Our major excavation tool is the proposed delivery date. Once this usually unrealistic date is ironclad, we use it to force short suspenses which result in inadequate planning, resultant lower quality RFPs and insufficient proposal analysis. The net result is that the government starts in a hole.

The next step, preparing a camouflage cover, follows almost inexorably from the first. Once we have dug the hole of inadequate preparation with the ironclad delivery date, we proceed to a frenzy of activity which appears designed to prove that there really is no hole. The force field that surrounds this activity is tremendous and grossly unbalanced. Institutional, career, and bureaucratic forces combine to develop momentum which overwhelms personal forces of principle, integrity and craftsmanship as illustrated in figure I.




I. Force Field Analysis Diagram

This mismatch generates the illusion that there is no hole. How could there be: All suspenses were met. All presentations were given. Costs and schedules have been developed.... At this point the camouflage blanket (about 1 micron thick) has been developed to throw over the hole as soon as we put in the sharp stakes. The sharp stakes are all the techniques we employ to make absolutely sure that falling in the hole will hurt us. Three of the most predominant are (1) basing other major programs on the success of the one we have just established under the 1 micron thick camouflage blanket, (2) only contracting for the first few units, leaving the remainder to be purchased on a follow-on sole source contract, and (3) providing very small positive incentives for outstanding contractor performance.

Now that we have successfully laid the trap, the camouflage activity begins to gain strength from the success of its past accomplishments and effectively blindfolds everyone who comes along. For example, if there is no hole there is no reason to discuss it with appropriate management. Situations with the potential for becoming serious problems are either ignored or put under the heading of contractor screw-ups to be dealt with by "holding his feet to the fire". The program becomes the child of the SPO and therefore not only can do no wrong but should, at the drop of a hat, be defended to the death. Obviously under these circumstances only the most optimistic forecasts are to be believed and any indications to the contrary should be shelved until all the facts are absolutely established. The blindfold becomes more and more effective as questions arise concerning the program. More questions generate more briefings which generate more briefing charts, the preparation of which uses the time which would otherwise have been spent on program analysis. This analysis is dangerous because it could penetrate the 1 micron camouflage blanket and expose the hole full of sharp stakes.

In this syndrome, analysis is not desirable because it could cast doubt on the viability of the program. It is certainly unnecessary since a 1% award fee is hanging over the contractor's head to make him do everything we wanted. And if there are any problems the contractor can just go to ceiling and get paid for cleaning up the details. Typical management steps which summarize the orientation that exists throughout this sequence of activities are:

1. Maintaining that there is no development in the program, just bolting together some off the shelf hardware and coming up with some software.
2. Don't surface it yet! It might kill the program.
3. Review 3 month old data to see how the author of the data says we got where he says we are.
4. Use this data to prepare the charts and backups and have two prereviews and six dry runs to check format, typing and graphics quality.
5. Prepare 300 charts each quarter for the review and approval cycle.
6. Be sure that at least 90% of the review time is spent on the 1% of the program that everyone feels comfortable discussing.

The buying-in syndrome is further aggravated in the government by the review and approval process. Actual comments taken out of their original context are grouped here to quickly create the buying-in syndrome perspective of the review and approval process.

"Your charts are not graphics quality."

Practically the only comment made before cancellation of a complex briefing on a series of integrated problems with a potential impact of nearly $1 billion.

"I don't care about foreign disclosure! How could you be so far behind?"

A comment made by one of the people responsible for a one year delay in the program due to inability to resolve the foreign disclosure question.

"Yes, you briefed that at each review, but that is not the official channel. Concurrence at the review is not approval!"

Part of the refusal to accept "review and approval" as justification for a course of action that proved to be inappropriate.

"The formats are changed for tomorrow's briefing."

"I think what the General wants..."

"Those were the wrong formats!"

Daily business.

The buying-in syndrome as it exists in the government side of the house is not a conscious malicious overt act of commission or omission. It is an almost infinite series of human actions conditioned by years of stimuli for which certain responses like "can do!" are expected or even demanded.

This demand is applied by the almost irresistable inertial force of the bureaucratic system pushing toward mediocraty. Stated simply it is the infinite compounding of each individual assertion that there really is a free lunch.

The next two elements illustrate the circumstances that are viewed as a buy-in and how contractor financial practices and government funding policies can be integrated to nurture the syndrome.

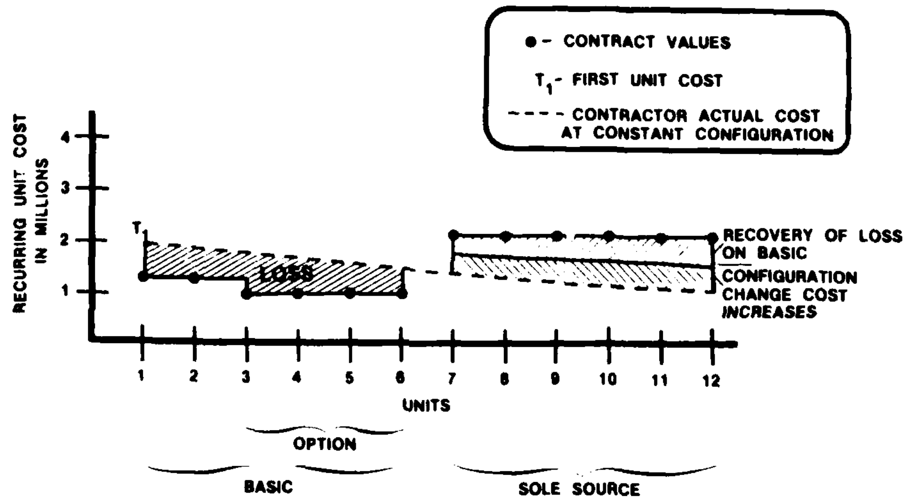
This following illustration (see figure II) is an actual example of an apparent "buy-in" using figures from a recent contract.

The situation is a basic contract for two units with an option for four more, followed by a sole-source contract for six additional units.

The learning curve expressed in the contractual values of the first six units is 30% steeper than any learning curve ever experienced in the history of the simulator program office. This unheard of learning curve is characteristic of a "buy-in". The competition surrounding the basic contract forces the contractor to make unrealistic bids in order to win the contract award. The contractor is therefore dependent on the sole-source (non-competitive) contract to recover losses suffered on the basic.

If you are wondering how a contractor can survive and even prosper while actual costs are over contractual ceiling on the basic contract, the following will explain how government funding characteristics make it possible.

As the contractor begins work on the first two units, billings are submitted. Being that the contractor's costs are higher than contractual amounts, billings would soon exceed the funding level causing expenses to be out of the contractor's pocket. For the contractor, the life-saving aspect is that the option is exercised by the government before the first two units are completed and before the contractor's costs have exceeded the funds available. With the exercise of the option comes an increase in the funds available. This incident happens again several months later, before the option units are completed, when the government awards a sole-source contract for six additional units and again raising the funds available.




II. The Buy-In

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SIMULATOR QUALIFICATION TESTING-SHARING THE RISKS

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ABSTRACT

The qualification testing of most Air Force aircrew simulators has stretched out far beyond the original test schedule estimates. The result has been additional costs and extensive delays in getting the simulators into the field in a ready-for-training status. This paper examines the historical data, identifies the persistent problem areas, assesses the inherent risks, and offers some recommendations for reducing the risks to both the government and the contractor.

## INTRODUCTION

The qualification testing period of Air Force simulators has historically been a very troublesome period in the acquisition cycle for both the contractor and the Air Force. Qualification testing is the Air Force conducted test and evaluation of simulators which is the equivalent of development test and evaluation (DT&E) in other acquisition programs. It is the "proof of the pudding" where we rigorously determine the contractor's compliance with the product specification.

When the time comes to start qualification testing, the contractor is aware that problems still exist, but he plans to keep a few steps ahead of the Air Force team rather than delay the start of testing. As testing progresses, the contractor comes under increasing pressure to stay ahead of the Air Force test team. Not only must he fix the known discrepancies before the team gets to that area of test, but he must also fix the newly discovered problems and maintenance difficulties which fall into the category of immediate "showstoppers." Experience shows that the contractor team is sooner or later overcome by events, and testing grinds to a slow walk and may even be forced to halt. This can hardly be a more inopportune time since the schedule reserves are probably all gone and the contractor is struggling just to preserve some portion of the profit he had originally counted on. At this point the "finger pointing" starts or increases in intensity and the whole mess is exacerbated by strong adversary relationships between the government and contractor. These in turn are further aggravated by frustration, 16 hour work days, and red ink on the bottom line. We eventually pick up the pieces and get back on track, but not without paying the price of a nonrecoverable schedule slip.

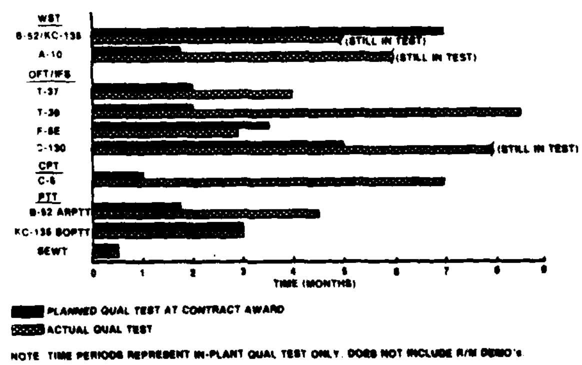
Obviously, this all too familiar scenario places both the Air Force and the contractor in undesirable positions. The contractor is motivated to minimize his losses while still getting the system out the door. It is easy for an error in judgment to result in prolonging the agony through the reduction of project resources and use of short cuts at a time when just the opposite approach should be taken. The Air Force, on the other hand, must tell users and the higher headquarters managers that the much needed training system will not be available as scheduled. This notification must be explained and justified up to the Air Force Council because of the impact on Air Force operational costs and readiness. It is easy to understand why the delay at the point of qualification tests results in letters of direction, claims, and other legal actions—all of which both the Air Force and the contractors would like to avoid.

## THE PROBLEM

In order to better define the problem, some research into the historical records of the Air Force Simulator Systems Program Office (SPO) has been accomplished. Data were surveyed on some 18 programs which have been or are being managed by the Simulator SPO. In each case we compared the planned qualification test period to the actual time spent, or in the case of the ongoing programs, the time spent to date.

The results for the completed or mature programs are shown in Figure 1. Note that in all cases except three, the qualification test periods exceed the planned test periods, in most cases by a significant amount. Although this result was not surprising, it was rather sobering to view our very poor track records on a collective basis.

QUALIFICATION TEST TIME
FIGURE 1




Those of you who have dealt with statistics and the necessary analysis to support meaningful conclusions know that the next step was to examine each program and ask the question, "Why did qualification testing extend beyond the planned period?" In an attempt to answer this question, several factors were considered:

-Number of SRs/TDs (Service Reports/Test Discrepancies) written

-Test versus fix time

-Requirements definition

-Data base inadequacies

-Quality of hardware design

-Quality of software design

-Spare core/time deficiencies

-Test readiness

-Contractor support during test

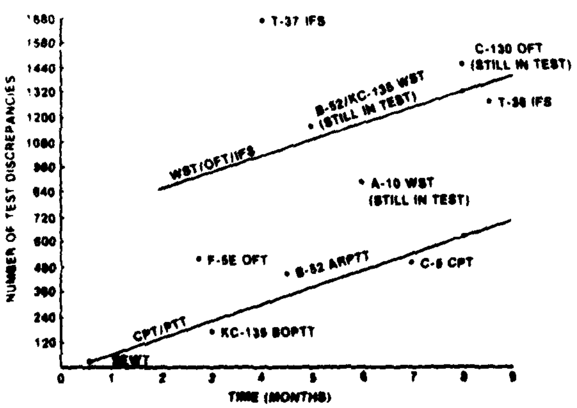
-Government management/support

-Subjective tweaking

Of the above considerations, the first two, number of SRs/TDs and test versus fix time, lend themsleves to quantification. The others are judgment calls and subject to disagreement, depending on perspective. Therefore, our analysis treated the factors in just that fashion. On the judgment side, we reviewed the records and talked to the Air Force program managers to reach a conclusion. It should also be noted that there is no intention to publish judgmental data which is critical or reflects poorly on the performance of any contractor. Consequently, our conclusions on the judgmental factors are not aligned by program.

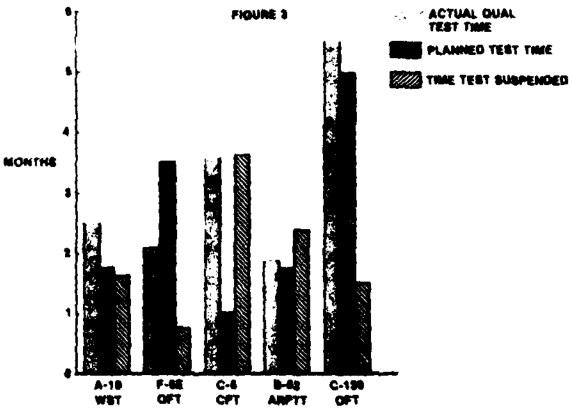
Figure 2 is a plot of the number of SRs/TDs versus the qualification test period. The diagonal lines are least square lines approximating the PTT/CPT (Part Task Trainer/Cockpit Procedures Trainer) devices and the WST/OFT/IFS (Weapon Systems Trainer/Operational Flight Trainer/Instrument Flight Simulator) devices. As would be expected, the more complicated simulators were subject to more writeups than the less complex PTTs and CPTs. It would appear in general that the systems which require more fixes must stay in test longer. Of course one can also argue that the longer a device is in test, the more writeups it receives. The noticeable difference between the nominal CPT/PTT line and the OFT/IFS/WST line is due to the relative complexity of the systems, and may also be driven in some cases by deficiencies in the design data base. It is worthwhile to note that the SEWT (Simulator for Electronic Warfare Training) and KC-135 BOPTT (Boom Operator Part Task Trainer), two of our on-time systems, had relatively few writeups. Even so, we did not find these data in themselves to be conclusive, nor did they reveal any results that drive us toward specific corrective recommendations.

TEST DISCREPANCIES-VS-TIME
FIGURE 2




The comparison of test time to fix time turned out to be somewhat more interesting and more conclusive. Figure 3 reveals that the actual time spent in test closely approximates the planned qualification test period in 3 out of 5 cases. Since we have not previously recorded the individual test and fix times specifically, we used only those programs for which the data could be gleaned from the records. It is believed that the close approximation between actual test time and planned test time supports our original estimate for total qualification test period where the assumption has always been made that the system will have successfully completed contractor testing and DCAS observed testing prior to going into Air Force qualification testing, and, therefore, will be largely fault free. As we examine the records and our own experience, however, we must conclude that our basic premise is false. Contractors do not always perform thorough independent QTP systems tests and the DCAS role is more QC oriented than performance oriented.

TEST PLANNING ACCURACY
FIGURE 3




JUDGMENT FACTORS
FIGURE 4

| PROBLEM AREAS | PROGRAMS 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| TEST READINESS | X | X | X | X | X | X |
| SOFTWARE DESIGN | X | X | X | X | X | X |
| CONTRACTOR SUPPORT | X | X | X | | X | X |
| HARDWARE DESIGN | X | X | X | X | | |
| REQUIREMENTS DEFINITION | X | X | X | | X | |
| DATA BASE (INADEQUACIES OR POOR USE) | X | X | | X | | X |
| SUBJECTIVE TWEAKING | X | X | | X | | |
| SPARE CORE/TIME DEFICIENCIES | X | | X | | X | |
| GOVERNMENT SUPPORT | | X | | X | | |

Figure 4 serves as a synopsis of the judgment factors as they were evaluated in six programs. The question we asked ourselves in each case is whether the factor had an impact on the extension of the qualification testing period. In all programs, the lack of test readiness and problems in software design were schedule drivers. You will note that lack of contractor support, which was defined as the lack of qualified personnel at the right time or in the correct numbers, also ranked high as a schedule extender. It is believed, however, that lack of test readiness made the personnel problem more acute than would normally be the case. Surprisingly, the subjective tweaking problems were seen as significant drivers in only three out of the six programs surveyed. It must be noted, however, that when subjective testing was relied on as a major part of making the simulator perform in an acceptable fashion, it had a substantial impact on the schedule. The collection and correct use of the data base was considered a significant factor in four out of the six cases. All of these four programs involved aerodynamic qualities and three of these four also suffered in test schedule because of subjective tweaking.

In summary, it is suggested that test readiness and associated contractor support rank as major problems. The data base, software design, and subjective tweaking appear to be interdependent problems with major impact. We will consider these problems in our discussion of risk and in our recommendations for improvement.

## RISK ASSESSMENT

The uncertainty of the time required to complete qualification testing presents risks to both the contractor and the government. These risks are not only associated with the test period, but are also linked back through the project to the very beginning. Actions of both the contractor and the Air Force throughout the life of a project are in many ways the result of risk assessments and perceptions. The following paragraphs present some analyses and insights into the problem of qualification testing as viewed from the perspective of risks.

Cost is obviously an area of risk that affects both the contractor and the government. The costs for the contractor are a direct function of the time in test. On the other side, any delays run up the government costs for test support, and more importantly, delay the availability of the system for training. From the contractor point-of-view, the government may test as long as desired, provided the contractor is being paid for the testing. However, since most contracts are FFP or FPIF, testing beyond the planned period results in a loss, or at best a shared arrangement due to the incentive provisions of the contract (assuming costs fall between target and ceiling on the FPIF contract).

There is a tendency to attack the overall problem of risk from a very limited perspective. Industry would feel comfortable with a cost reimbursement arrangement for the test period. However, that would place all the risk on the government. On the other hand, a FFP contract shifts all risk to the contractor. From the contracting view, the risk should be proportional to the ability of each party to control that risk.

Test cannot be viewed to be bounded by just that time period during which the qualification test occurs. It is, indeed, much broader than that. The success or failure during qualification test starts at the very beginning of the formulation of requirements and does not end until the completion of the qualification test period. What we must do in considering the risk is to take a systems approach, e.g., look at each element of the acquisition process that affects test and assess the individual and collective impacts on risk.

### Requirements Definition

The definition of training requirements, hopefully through the ISD (Instructional Systems Development) procedure, becomes the basis for the determination of the system to be built. The training requirements drive us toward a specification which describes a device somewhere along the continuum from a PTT to a full WST. The intended use of the device in training may necessitate a full fidelity approach or may allow little resemblance between the trainer and the actual operational hardware. It is the full fidelity trainer that this paper will emphasize since the authors have little experience with the other types of trainers. Furthermore, it is trainer fidelity that we normally strive for, and it is this same fidelity that is the source of the risk for both the government and the contractor. A large portion of our testing activity is to prove that the simulator looks, feels, and performs just like the operational hardware. One of our favorite specification references reads, "Simulator performance characteristics shall not be perceptibly different from characteristics of the real world aircraft."

If the performance of the operational hardware, which we seek to simulate, was fully defined in quantitative engineering terms with no areas of uncertainty, the risks in designing, building, and testing a simulator would be simply those associated with the application of appropriate existing technology to achieve the desired result. These are the risks which every contractor must take in doing business. However, the risk in achieving acceptable performance (within planning estimates) increases dramatically when the performance of the device is poorly defined, or in some cases not defined, and the contractor must guess at what the final performance should be.

### Data Base

The data base for simulator design is usually the responsiblity of the contractor. He is required to collect existing data from any available source in order to firmly establish the design basis for the simulator. We assist in this collection process by requiring that the airframe contractors supply data to the simulator contractors. However, the required data are not always complete or in a format which is usable by the simulator contractors. These deficiencies result in risks to the simulator contractors since the quality of the data can only be ascertained through detailed analysis--a process which seldom occurs during the proposal stage.

It has been suggested that all baseline data be gathered and certified by the procuring agency to relieve the contractor of the risk over which he has only limited control. This has been considered, and is, in fact, being done by some government agencies. However, in order for the government to collect and supply the data to the contractor, a team of engineers, technicians, and clerks must be dedicated to the task, and the government must assume the risk associated with the data base process. This risk in turn spills over into the design process since the design is data base dependent. It is our opinion that the contractor, as the simulator design agency, can perform the data task in a more efficient manner, and in general, should be held responsible for obtaining the data needed for design. It is recognized, however, that should a number of contractors need to operate from a common data base in either a cooperative venture or a competitive one, it may be appropriate for the government to directly control the data base.

Design

The risk associated with the design process falls squarely on the shoulders of the contractor. It is the contractors expertise in this area that serves as a foundation for his business. The Air Force has no intention of designing simulators for which industry is being paid to design. This statement is not meant to deny the fact that we place a number of constraints on the design. But the performance of the simulator during test, as it relates to design, is a contractor responsibility and any performance discrepancy which is clearly not in accordance with the available data must be fixed by the contractor.

Qualification Test Procedure (QTP)

The QTP is frequently an area of contention between the government and the contractor, and is, therefore, a source of risk. The government wishes to perform a rigorous series of tests to assure that the simulator meets every requirement of the specification. Although the contractor agrees in principle, there is a tendency to feel that a less thorough test program will accomplish the same objective. The preparation of the QTP is frequently delayed until the very last minute. This delay results in compression of the effort, and inadequate time for review, revision, and approval. We, therefore, enter qualification testing without full definition of all the tests and corresponding success criteria. These uncertainties lead to disagreements and less efficient implementation of testing.

Test Readiness

The test-fix-recheck process is central to the problem of stretchout of the qualification test period. We presented data in Figure 3 which was the basis for our conclusion that our test estimates are not all that bad, but that unscheduled downtime for fixes is the real culprit in the schedule slips. In other words, if the machine could undergo testing without the resulting writeups, our test estimates would be fairly accurate. It is, of course, unrealistic to expect that no writeups will be necessary. However, if a system has been thoroughly and successfully tested by the contractor and DCAS prior to the official start of government qualification testing, the testing should progress smoothly with few interruptions to correct deficiencies or equipment failures.

Tweaking

Perhaps the biggest risk to the contractor stems from the contract requirements to make it fly like the aircraft--particularly when the success criteria cannot be established on a firm quantitative basis. What we must deal with then are subjective evaluations by Air Force test personnel. This evaluation process is obviously person dependent and can lead to numerous tweaking and redesign efforts because of non-repeatable tests. The separation of interactive variables becomes cloudy and very dependent on the capability of the Air Force test pilot. The tests can easily stretch out and frustrations on both sides run high since progress is slow and there is no way to fully establish responsiblity of the stretchout. Industry has accepted this risk in the past, but cost overruns have reduced the willingness to continue in this fashion.

## RECOMMENDATIONS

Having examined the problem and the risks, it is now appropriate that we consider how we should approach the test period in the future to better assure schedule compliance, avoid additional unforeseen costs, and share the risks in a more equitable fashion. The following paragraphs address and briefly explain a number of recommendations.

Requirements

It seems elementary to state that requirements should be defined by the operational command and that these requirements should be clearly developed and reflected in the RFP. However, our experience has shown that much work still needs to be done in the requirements area. The ISD process is being emphasized and further defined in an attempt to attack the problem. High level visibility is also being focused through the actions of the Air Force Simulator Advisory Group (SAG) and by the rejection of some Program Management Directives (PMDs) for further definition before action will be taken. We are also trying to improve our specifications and reduce the potential for misunderstandings. Our program teams have been directed to avoid informal changes which can have an impact on cost or schedule (including test) or lead to later disagreements, claims, etc. In other words, we must use existing techniques to formalize all changes. Industry needs to cooperate fully with us in this attempt to avoid test problems which are requirement related.

Data Base

The proper collection, analysis, and utilization of the data base is absolutely essential if we are to make significant progress in reducing the risks associated with qualification testing. What we need is a means of moving from qualitative testing toward quantitative testing. Through proper use of the data base we can quantify the expected results for most tests, and in some of the remaining cases, establish design tolerances which will allow for relatively easy qualitative tweaking to achieve the required fidelity. There may still be some areas where the data are of little use, but we can at least recognize these and avoid surprises.

The data base becomes the support structure for all subsequent design and test actions. It must be as complete as possible. Where holes exist, they should be filled by such actions as further data search, actual tests, or estimates in collaboration with government representatives. If data are inconsistent, the contractor should, through analysis, resolve the inconsistencies or seek government resolution if judgment must be exercised. The completeness and accuracy of the data base cannot be overemphasized since it will serve as the necessary resource for both design and testing.

Design

The design must be traceable to the data base. Where data are precise with little variation, the design can be accomplished with little allowance for tolerances or tweaking. If data so indicate, the design should be accomplished in such a fashion as to permit significant performance adjustment without total redesign. Experience and technical insight into simulator performance has shown that there are three categories of data which require different design approaches:

- firm, precise data to support design

- suspect data with large spread

- extrapolated or estimated data in substitution for actual measurements

Design and test to the first category of data is straightforward. Data with large spread requires a more cautious approach to allow for adjustments in order to meet required performance. Estimated data derived to fill holes in the data base provide design guidance but obviously place the designer in a risk position with respect to meeting acceptable performance. Creative approaches to allow easy changes are in order to reduce the risk.

Qualification Test Procedures (QTP)

The QTP should be prepared in parallel with the design effort and should be closely correlated with it. When a design is accomplished to meet a given parameter or performance curve, the testing procedure to prove or confirm that the design is correct should be accomplished also. Note the very important point that the design and the testing should both be related to a common baseline contained in the approved data base. Therefore, the ultimate success criteria to be used during subsequent testing, including qualification test, are the same as the original design objectives and the loop is closed. Of course, it is not always that easy. There may be many interim steps in both design and testing before a primary performance criterion contained in the data base can be achieved. Furthermore, the interaction of parameters, particularly in the total realm of aerodynamic performance, can make both the design and the testing a very complex problem. Nevertheless, in order to get a handle on the qualification test process we must quantify to the extent possible the test goals and the logical source for that quantification is the data base which serves as a foundation for the design.

One further point needs to be stressed. A poorly prepared QTP, produced at the last minute in isolation from design, invariably has a negative impact on test. The procedures simply don't work and the goals, objectives, and success criteria are not correlated with the design and data base so that orderly, effective testing can be accomplished. As a result, the test team is forced to set aside the official plan and create a new plan which is workable and will yield the desired results. This slow, laborious process is wasteful of valuable test time. In addition, there is a tendency to substitute subjective success criteria for the objective criteria which are contained in the data base. In other words, a poorly prepared QTP increases the risk during test for both the contractor and the government.

Test Readiness

Government and industry collectively have done a poor job in determining readiness to start qualification testing. Perhaps our different persepectives have led to different expectations from the qualification testing. Industry may be primarily driven by cost and schedule while still wishing to field a simulator of acceptable performance. Government, on the other hand, places simulator performance at the top, with cost and schedule a close second. These different priorities are more understandable when we recognize that our current contract structures lead to limitation of government liability to contract ceiling or price (FPIF or FFP). Furthermore, the government acquisition agencies have firm commitments to the operational units to provide high quality simulators which meet original requirements. Anything less will likely fail to be used to full advantage and the result will be a waste of taxpayers money.

When we enter qualification testing the government representatives expect to test a machine which is prepared to be put through its entire operating envelope to demonstrate full compliance with the specification. This testing should require few changes or adjustments to the system during the tests and these should largely be a result of the minor adjustments or tweaking required to make the simulator respond correctly in the more subjective areas where quantitative data are unavailable or inadequate. If this readiness goal is to be achieved, we must make several changes in the way we currently do business:

A complete, well-defined design and test baseline must be established

- Discipline must be exercised to relate actions to the baseline

- The contractor must accomplish his own tests before government qualification testing in order to sort out the problems and make fixes to bring the simulator into compliance with the specification.

This approach does not mean that government experts will not be available to assist where they are needed in preparing the system for qualification testing. Recent contracts have committed government testers to provide early assistance in evaluating the simulator performance, particularly in the realm of aerodynamics. It is our impression that this government assistance has been well received and is valuable in catching problems at an early stage. The use of on-site government representatives (DCAS or similar) to go through the QTP with the contractor can be much more effective than it is now if QTPs are better prepared and provide a better measure of system readiness.

What must be done if we are to avoid the test-fix-retest syndrome is for contractors and government to make a commitment to use the qualification test period as it was intended to be used--a time to make the thorough tests to assure that contract specifications are met, rather than a time to make the system meet the specifications.

Qualification Test Period

Assuming that things have been done correctly up to this point in the project, the qualification test period should be anticlimactic. The major system problems will have been sorted out and corrected during the contractor and DCAS testing periods. All that is left to be done is thorough confirmation by the Air Force test teams that the system is in compliance with the data baseline and a final tweaking period to make minor adjustments in order to satisfy those subjective feel judgments which could not be quantified or accurately predicted by the government/contractor technical team.

As a check on test readiness it is suggested that a functional check flight (FCF) be designed and included in the QTP to provide a quick overall system check prior to starting the detailed test procedures. This FCF would be accomplished after the software cold start is complete. Should major problems still be evident, the contractor would be given time to make corrections before starting the detailed subsystem tests.

After tests are completed to confirm that the system meets the QTP success criteria as related to the original data base, the period of subjective testing and adjustment would begin. It is at this point that it may be argued that we should depart from the traditional way of doing business and find some means of more equitably sharing the risk associated with making the system fly like the aircraft. At one extreme is the position that the contractor has no way of predicting or controlling the actions which will be required by the government to accomplish the required performance. At the other extreme is the argument that the contractor through experience and insight into the necessary simulator performance and through assessment of the data base and requirements should be able to predict the extent of necessary tweaking.

We submit that the real world lives somewhere between these extremes. There is little doubt that a capricious and arbitrary government test team, should such a team exist, can drive subjective testing for an unnecessarily long period of time and run contractors costs beyond expectations. An inadequate data base can, of course, load the testing with subjective criteria which can lead to the same result. The current constraints on such activity are the contractor's reluctance to cooperate and the need by the government to get the system into the training inventory. On the other hand should the government agree to accept all responsibility for the subjective test period, the contractor would have little motivation to take the necessary steps through data collection/analysis and heads-up design to avoid an extended period of subjective testing and tweaking. There might even be a contractor tendency to unload activity into the subjective test area rather than expend the effort to avoid it. It should be noted that even under the full contractor risk scenerio currently in effect, it can be argued that some contractors are not making a maximum effort to stay away from subjective tweaking.

Contracting Arrangements

What then is the answer? How can we structure our contracts to more equitably share the risks associated with simulator development which culminates in the qualification testing period?

-Maybe a cost type of contract for the subjective test period is more appropriate in light of the risks involved.

-Perhaps better management of risks could lead to reduction or elimination of them to the point where FFP is reasonable.

-Maybe it is simply better utilization of FPIF type contracts which, after all, allow for the sharing of risks.

-Maybe a definition phase is required to allow for data collection and analysis.

-Perhaps the FPIS contract can be applied to provide a flexible technique in more closely aligning responsibilities and risks.

Let's briefly look at each of these alternatives in our search for a better way.

A cost type of contract for the subjective tweaking period does not seem appropriate because it places all of the risk on the government and does not provide any incentive for the contractor to minimize subjective tweaking. In fact, it would provide an incentive for the contractor to maximize his profit under a FPIF or FFP basic contract and unload the other effort into the subjective test part of the project. This approach would be difficult to control from the government point of view.

If we have a firm and complete data baseline to serve as a foundation for our entire design and test activities, there is little risk involved and contracting guidance would drive us toward a FFP arrangement. Our experience to date has shown that complete and accurate data do not exist for those simulators which we have built. However, it is our opinion that we have failed to make optimum use of the data which has been available to us. If we had done so, the risks on past and existing programs would have been reduced. In the future, it is possible that careful planning with the acquisition agency for a new aircraft might allow us to obtain most of the required data which could serve as a foundation for a FFP approach. It is probably unrealistic to totally eliminate all risk associated with subjective testing, but the risk might be minimized to the point where FFP is reasonable. This approach is at best in the future and may never be feasible if concurrency of the simulator and the aircraft continues to be a goal. Nevertheless, better use of current data will reduce risk but not eliminate the problems associated with our present contracting structures.

Better utilization of our FPIF type contracts may help resolve the problem. Present experience, of course, indicates that most contracts go to ceiling and contractor's costs actually exceed ceiling. Obviously, the sharing of costs and risks between target and ceiling is not providing the cushion required in our current way of doing business. Perhaps our negotiated targets are too low, or maybe we are simply doing a poor job of management. Competition has doubtless forced many in industry to ignore risks and go against their own better judgment in making BAFOs (Best And Final Offers). Assuming the subjective tweaking is the unknown risk which is being suppressed, we have considered defining and setting aside this period of testing in the early stage of the contract and seeking to establish an equitable share ratio over and beyond the basic contract should the ceiling be exceeded. For example at PDR or CDR (Preliminary or Critical Design Review) we would have an in-depth review of the data base/analysis and identify those parameters which would likely be subject to qualitative tweaking. With this knowledge we would negotiate some share ratio based on our risk assessment which would come into effect only if the ceiling of the basic contract were exceeded. This share ratio would place more burden on the contractor than the basic contract share ratio in order to encourage completion of the project within ceiling and discourage the shifting of work from the basic contract to the above ceiling sharing arrangement.

There are some problems with this proposal:

-It's open ended

-Government budgeting would be difficult

-It may be tough to reach agreement on the above ceiling share ratio

-We would have to find some way to identify and contain the basic low risk work within the primary FPIF contract

Because of the above problems, the contracting community does not support this approach.

It has been suggested that the big unknown facing industry at the time of proposal and negotiation is the availability of complete and accurate data on which to base the simulator design and testing. Furthermore, because of the magnitude of the task to collect and analyze the data, contractors have neither the time or the resources to resolve this unknown during the proposal phase. In order to reduce the risk associated with the data base, it has been suggested that a definition phase contract be awarded. This approach would remove much of the risk, but it would also extend this time required to provide a training device to the field. Since the time delay between definition of requirements and ready-for-training status is already considered much too long, this approach cannot be recommended.

Another way of contractually recognizing the problem of the data base availability and content, along with its impact on testing, is through the use of a FPIS arrangement. This contracting technique allows the target to be reset at some well defined contract milestone. In the case of the simulator, we could define the reset to occur at PDR or CDR, a point in the program where we should have the data base problem under control and, therefore, have a much better idea of the subjective tweaking required to achieve our fidelity objective. Although ceiling and share ratio would remain the same, the adjustment of target would allow full recoupment of some costs and reduce the risk to the contractor at a point when those risks are more fully defined. This FPIS approach is recommended as the most appropriate method to more closely align the risks and responsibilities involved in the simulator acquisition process.

## SUMMARY

The historical record and our own experience indicates that qualification testing is requiring much more time than we include in our program plans. This extension of test time impacts both contractor costs and system deployment. The problem of test extension is not limited just to the test period but permeates the entire program starting with requirements definition. Our look at the principle elements of requirements, data base, design, qualification test procedures, test readiness, and actual tests, as these relate to the problem, has led to a number of recommendations to improve our performance and reduce the risks for both government and industry. The importance of the data base as a foundation for subsequent design and testing activity has been stressed. We have examined the risks and concluded that they can be reduced by better government/contractor management of the program and through more suitable contracting arrangements. Specifically, it is recommended that an FPIS approach be used with reset at the PDR or CDR milestones in order to make allowances for unknowns relative to the date base and the effects of these on qualification testing schedules.

The recommendations contained herein will not serve as a panacea for all the problems we jointly face in trying to provide the best possible aircrew simulators to our operating forces, but it is hoped that these ideas will serve as a catalyst for further improvements in the way we do business, particularly as they relate to the tough problem of qualification testing. Let us not forget that we have a responsibility to ourselves and this country to provide the means for our aircrews to be the best trained in the world. This objective demands our continued efforts to produce high quality simulators, which are delivered on time and within cost. Solution of the qualification test problems will be a giant step toward this objective.

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ON-LINE CONFIGURATION MANAGEMENT

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ABSTRACT

ON-LINE CONFIGURATION MANAGEMENT: Configuration Management is covered in many books and articles and is described in detail for development and test of systems which are either all software or all hardware. In real time simulation which involves integrated and, many times, interactive hardware and software, plus human interaction with instructor and/or students, a new level of control is required called hardware software integration/test. In addition, subjective customer evaluation and acceptance may extend this period indefinitely. This period of test and evaluation could result in elapsed time of half the project schedule and is usually where all the budgets/schedules go down the tubes. This paper describes an approach to on-line system configuration management, starting with a prototype baseline system ready for hardware software integration.

## INTRODUCTION

An Industry/Government meeting held on November 26, 1979 prior to the first interservice/industry training conference concluded with a list of initial planning and acquisition issues for a panel discussion during the conference. The purpose was to gain a better understanding of problem areas, to identify and discuss probable causes, and to reach some agreement on possible recommendation to improve performance. Under the topic "Contractor Performance," the following problem areas were described:

"The need exists for the development of more definitive software management plans with milestones adequate for monitoring developmental progress. Concomitantly, determinative plans for the integration of software with hardware is required. Frequently either software development lags and/or extensive integration problems are encountered; the resultant effort to catch up or correct causes delays and additional costs."

"Practically every major training device program has experienced difficulty in the development of software and its integration with hardware. Underestimating software development adversely impacts time, schedule, and performance requirements, and creates serious life cycle support problems. What can be done by contractor management to place the required emphasis on software development?"

"Status reporting systems are only creditable if they factually state progress on the program and highlight critical issues in management or engineering that require decisions. What can be done to improve the quality and timeliness of status information provided by contractors?"

This paper addresses these problem areas, particularly the last paragraph on reporting systems, as they occurred during the development of the T-44 Ope ional Flight Trainer (OFT). The T-44 OFT develo nt program was the first project which applieu the on-line configuration management technique.

## DEFINITIONS

Reference Figure 1 for pictorial presentation.

1. On-Line - The complete hardware/software system under operation and test in real time.

2. Verification - Test the computer program to ensure that it satisfies all performance and design requirements; e.g., software engineering tests.

3. Validation - Test the computer program to ensure that it operates properly in the system environment and that it satisfies all system requirements; e.g., system engineering tests.

4. Hardware Software System Integration - This type of testing executes the computer program in a completely real (on-line) environment utilizing actual hardware. This test demonstrates that the computer program satisfies all requirements of the program performance specification while being executed in a real system environment.

5. Acceptance Test Procedures (ATP) or Certification - This type of testing makes use of the computer program after it has completed system hardware software integration. This test is intended to exercise all subprograms of the computer program in consonance with the hardware. These tests certify that all software, hardware, and system requirements have been satisfied. These tests are defined in the Acceptance Test Procedures document. Figure 1 shows the relationship of verification, validation, and certification testing.

## CONFIGURATION MANAGEMENT

Configuration management (CM) is a discipline traditionally applied to the development of hardware systems or to the development of hardware elements of hardware software systems. Its application in connection with other disciplines leads to orderly and structured system development. CM is generally concerned with the consistent labeling, tracking, and change control of the hardware elements of a system. Software configuration manage-

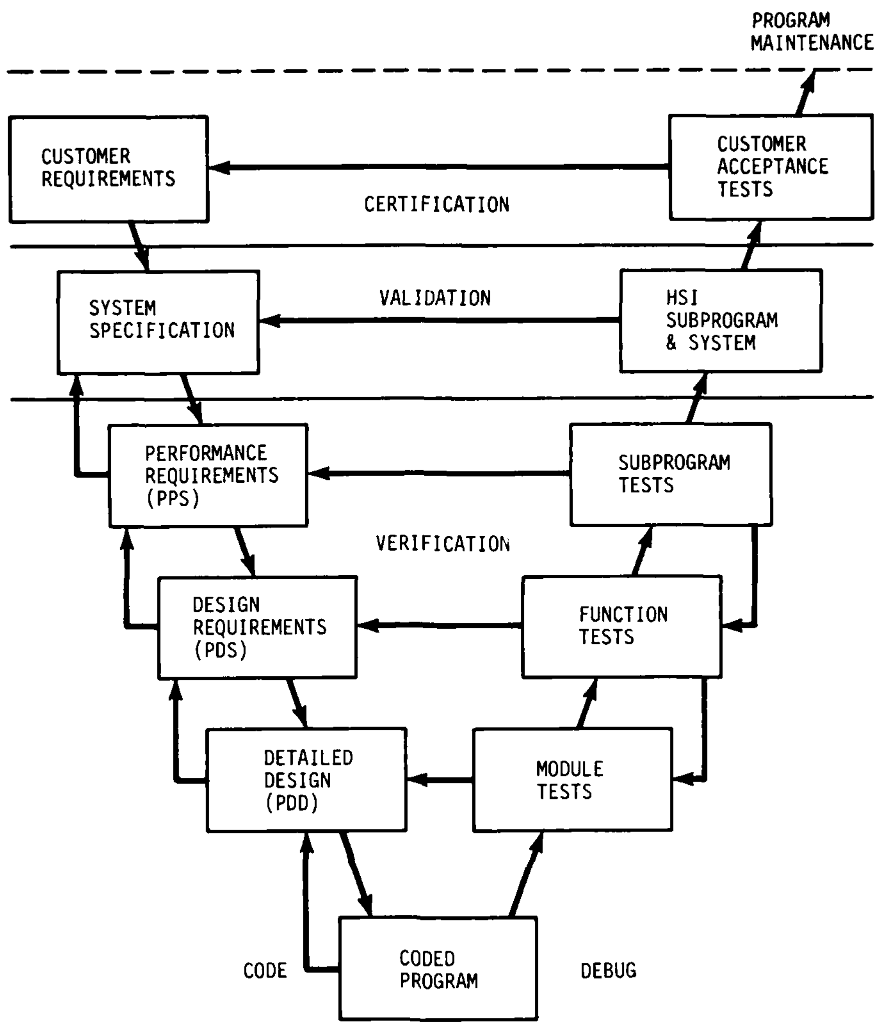


Figure 1. Verification, Validation, and Certification

ment is CM tailored to a system, or portion of a system, predominantly comprising software or firmware.

Figure 2 depicts the stages of the system life cycle. Although each stage is equally applicable to hardware and software, the differences between hardware and software development and production give rise to different specific requirements for managing the software life cycle. Each stage of development culminates in a baseline, (Figure 3) a point at which management has the opportunity to view the system in detail in order to examine its integrity - that is, its adherence to and satisfaction of the operational requirements.

After both hardware and software become independently operational, a period of hardware software integration (HSI) begins and continues until all acceptance testing is completed and the device validated. The basic four components of configuration management will be addressed during HSI and acceptance testing as depicted in Figure 4.

Configuration Identification

Identification during hardware software integration and acceptance testing is well defined and takes place at the subprogram level. A subprogram is a subdivision of a computer program that accomplishes an entire set of

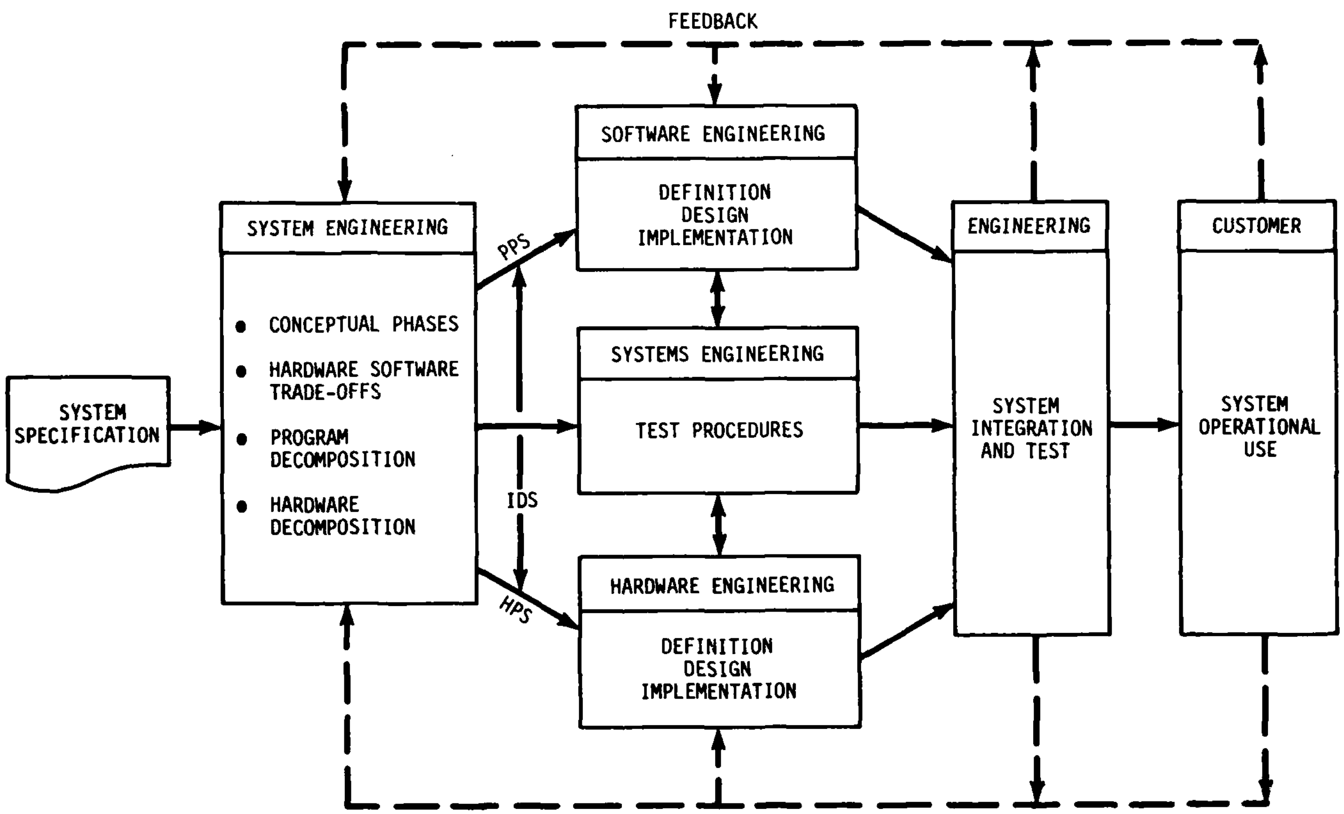


Figure 2. System Life Cycle

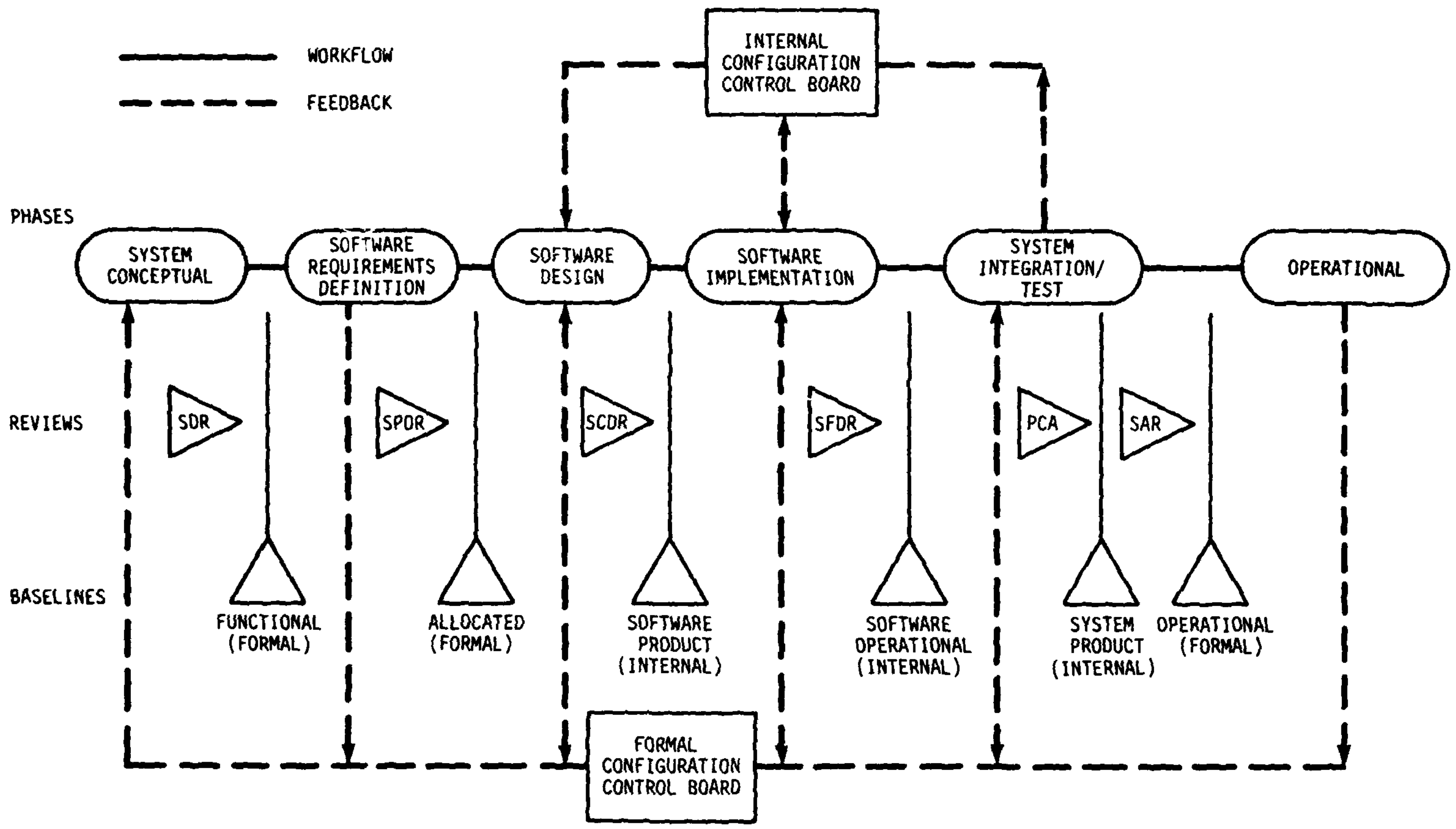


Figure 3. Computer Software Life Cycle

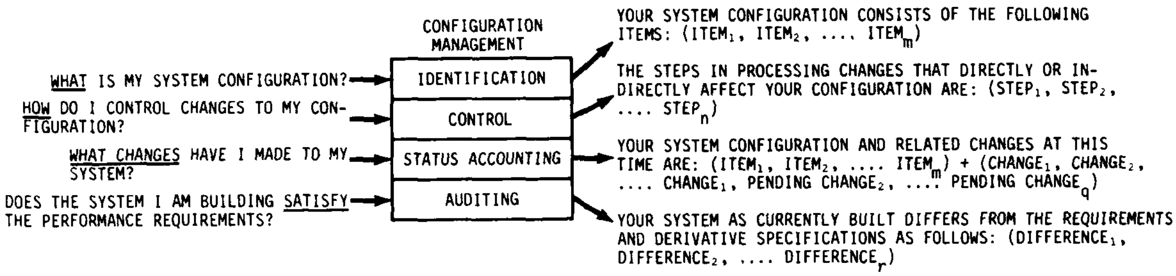


Figure 4. The Four Components of Configuration Management

program performance requirements; e.g., fuel system. Therefore, it is a specific testable entity.

The tests are also well defined. A complete and approved Acceptance Test Procedure is utilized (and proofed) during this period of configuration management. Note that during all the testing we are asking the question, does the system satisfy the performance requirements? The whole testing philosophy is keyed to the audit concept of discrepancies; e.g. "The current system differs from the requirement as follows!" The audit is continuous. The schedule is keyed to the audit.

On the T-44 OFT, the schedule was developed by the project engineer and based on the estimates to complete obtained from his engineering staff, the status of the hardware, and the subprogram interdependencies. Each subprogram was identified in accordance with the approved acceptance test document and organized in schedule format for each of two shifts. Included on the schedule was a weekly summary status accounting of discrepancy reports (DRs). Figure 5 indicates graphically normal DR generation and abnormal DR generation. Note that a normal curve peaks out and drops off towards zero. A glance at the schedule (Figures 6, 7, 8, 9) provides the observer with a top level audit and trend. For example "Are more DR's being generated than fixed?" Having established what the configuration is and a method of determination of status, we will now look into methods of control.

## Configuration Control

Controls take two significant forms; the first is control of changes to the software configuration and the second is control of the status of testing. On the T-44 OFT the problem was compounded somewhat by having two devices (trainers) entering HSI at approximately the same period in time. Therefore the following management procedure was established.

Software Configuration Control. Every Friday morning prior to the 0800 shift, system 1 was backed up on magnetic tape. System 2 was made identical to system 1 by restoring system 1 backup tape.

System 1 was considered the master system. All other systems were considered as test beds for changes. It was the responsibility of each software engineer to update system 1 with any modified models or programs by informing the librarian of the files to be moved to system 1 and on which system they currently resided.

All system discrepancies (hardware and software) were to be reported using the Discrepancy Report (DR) form (Figure 10). The filled in form was given to the librarian who was responsible for assigning a DR number and entering it in the DR master log. Hardware DR's were then passed on to systems personnel for handling. As each DR was corrected, an entry to that effect was made in the master log. The DR was then defined as "TESTED". A DR could only be defined as "CLOSED" when tested and signed off by the project engineer.

As each DR was tested and closed, the backup tape number was recorded to provide traceability for all changes. All changes were in the form of source code updates. No patches!

A job accounting system incorporated into the vendor's computer operating system was used as a general accounting ledger to track all changes. The accounting file was listed every Friday morning and also saved on the system backup tape. After the file had been saved, it was purged and made ready for the next week. The job accounting listing, the backup tape number, and the DR masterlog provided an excellent means of managing the progress of the project and controlling the configuration of the system.

Testing Status Control. System test control was established by setting up good communications and by test status documentation.

Communication:

- Established weekly all hands meeting.
- Wrote minutes for review.
- Determined significant problems.
- Established responsibilities and action plans.

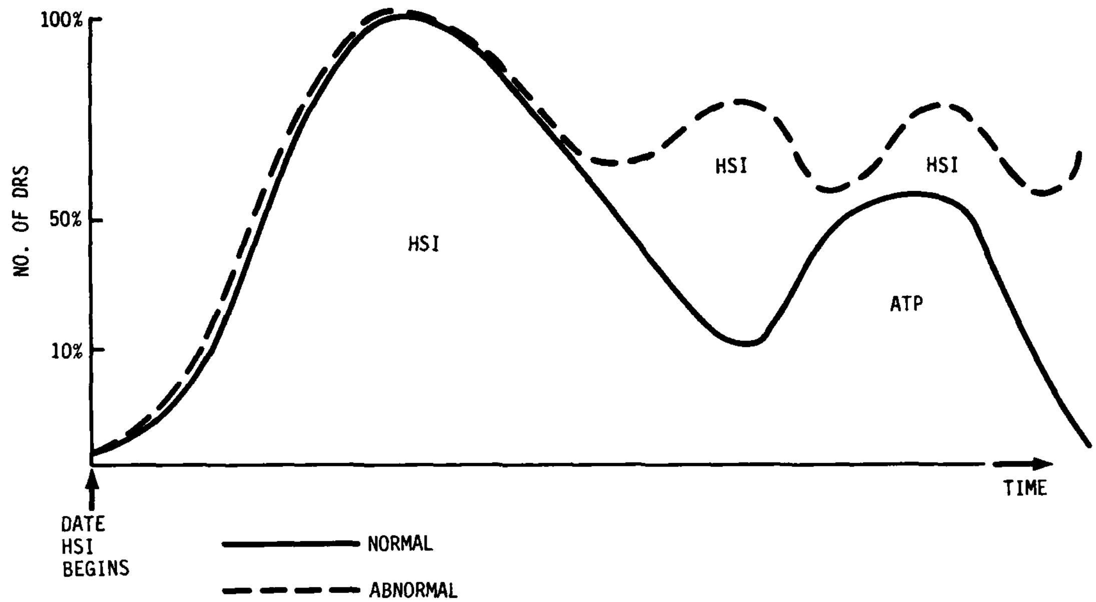


Figure 5. Normal/Abnormal DR Generation

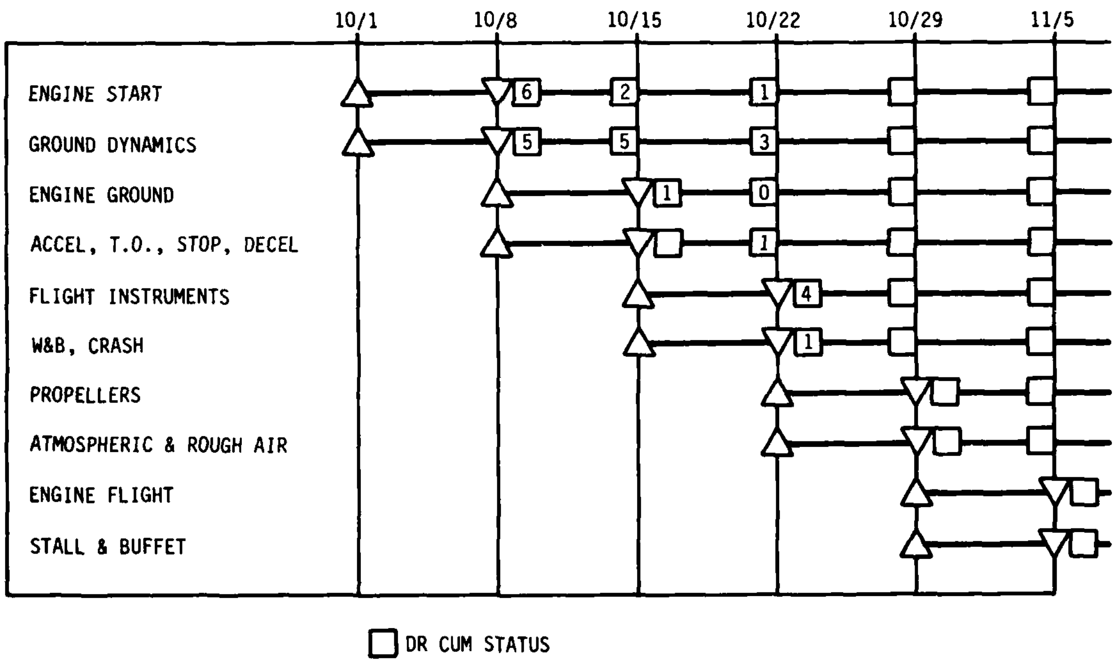


Figure 6. T-44 System Integration and Evaluation Shift 1 (Month 1)

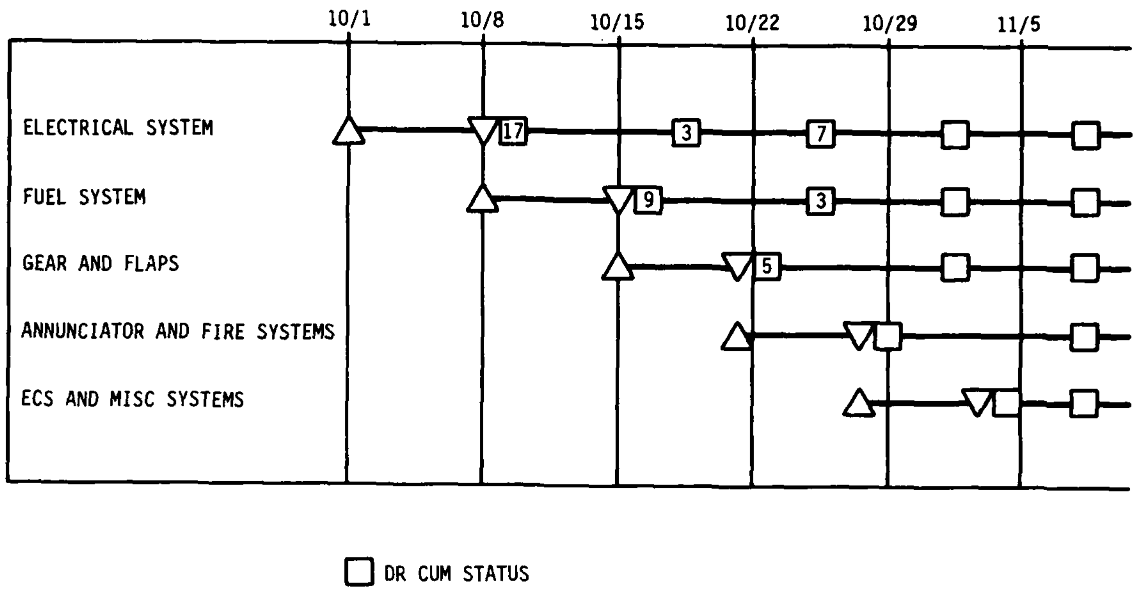


Figure 7. T-44 System Integration and Evaluation Schedule Shift 2 (Month 1)

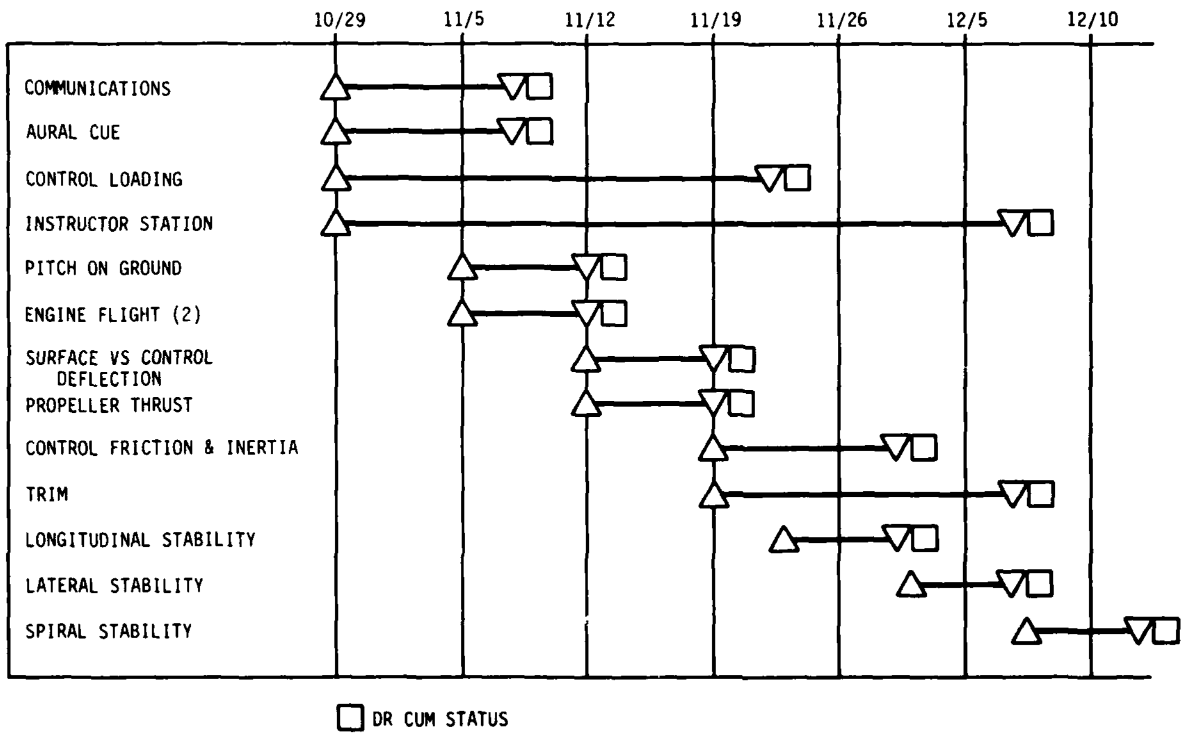


Figure 8. T-44 System Integration and Evaluation Shift 1 (Month 2)

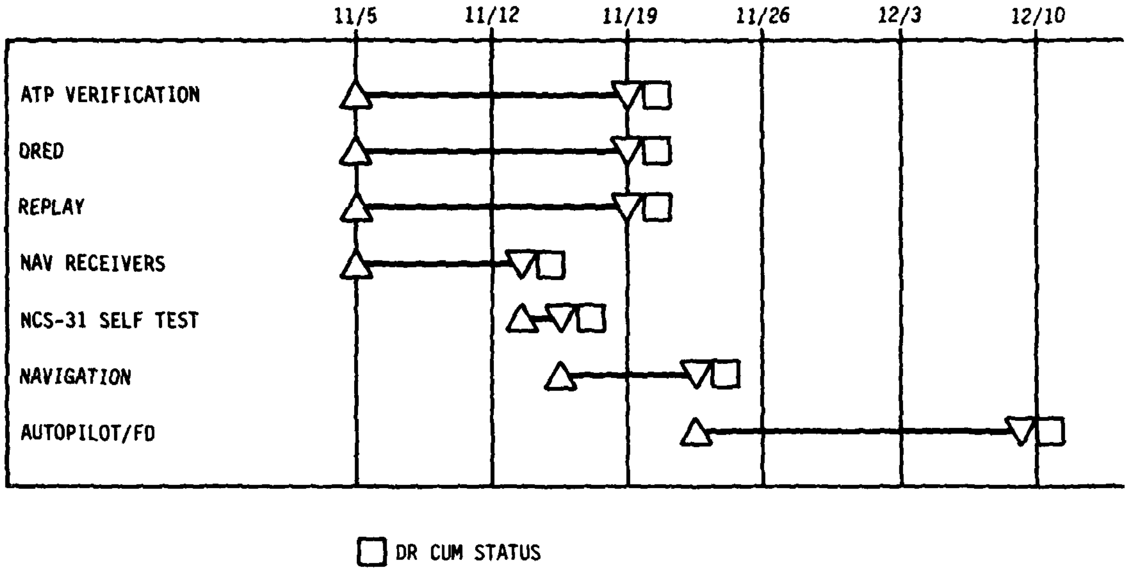


Figure 9. T-44 System Integration and Evaluation Shift 2 (Month 2)

DISCREPANCY REPORT (DR)

PROJECT: DATE:

ISSUER: PROBLEM NO.:

RESP. ENG.: REF:

TYPE OF PROBLEM

( ) HARDWARE: SYSTEM # ______ ( ) SOFTWARE: SYSTEM ____________

STATEMENT OF PROBLEM

CORRECTIVE ACTION TAKEN

TESTED

DATE __________ TAPE # __________ ENGINEER ____________

DATE __________ TAPE # __________ ENGINEER ____________

COMMENTS

Figure 10. Discrepancy Report Form

Accounting:

- Set up test schedule keyed to discrepancies.
- Updated discrepancy form.
- Librarian had full authority and responsibility for accounting.
- Job accounting system incorporated into the operating system.

The status accounting report, described below, was utilized at the weekly meetings and proved to be the key ingredient to successful communication. Each person knew his responsibility and management visibility allowed the decision-making processes to work!

## Status Accounting

In order to keep track of all hardware and software problems which occur during Hardware Software Integration (HSI) or the Acceptance Testing Procedure (ATP), a Discrepancy Report (DR) is filled out. As each discrepancy is reported, a control number is assigned by the librarian and entered in the master log. The function of this log is to keep a record of all DRs and present this information in various ways.

The DR Status Accounting Report, written in FORTRAN IV, will operate on the project computer system in the interactive mode. This interactive program reads a master log entry in card image format, processes the input data, and prints a hardcopy output report as specified below.

The program can be applied to any trainer project by preparing an appropriate set of inputs. The program input file (project data base) can be divided into two sections. The first part (systems section) describes the major systems of the trainer and generally correlates with the computer subprograms. The second part (data section) of the file represents the DR data base. It is information that is taken from the DR log and added to the data base periodically. Thus the systems data remains fixed for a given project while the DR data base increases as the project progresses.

The first record of the systems section contains the name of the program (i.e., T-44, C-130, 21E17, etc.). Next are the system descriptions, one per record, along with a unique system letter. After the system description comes the data section. This information includes the DR number, system letter(s), initials of the assigned engineer, date tested (when applicable), failed testing or waiting for parts indicators, date closed (when applicable), a brief description of the problem, and the number of the backup tape on which the problem solution first appears.

The program reads the input file and prepares the master DR log which contains the status of each DR printed out in numerical order. A summary table is compiled which lists each system, the number of open, closed, or tested DRs, the total number for each system, and the totals for the whole job.

The information is then resorted. The first resorting procedure prints out all DRs which are not closed. The next sort will print out a listing of all DR's which are ready for testing. The non-closed DRs are then resorted again for a third and fourth time and printouts are made by system and then by assigned engineer.

Last, another table is compiled showing the DR totals - open, tested, closed, and totals - by responsible engineer.

Figure 11 identifies the format and contents (as described above) and indicates that the loop is closed by summarizing the DR's by subprogram on the schedule.

1. FORMAT:

| DR. NUMBER | SYSTEM AFFECTED | RESP ENG | DATE TESTED | DATE CLOSED | DESCRIPTION | STATUS | TAPE NO. |
|---|---|---|---|---|---|---|---|

2. CONTENTS:
   - SYSTEM LEGEND - IDENTIFICATION
   - MASTER DISCREPANCY LOG
     - SYSTEM SUMMARY STATISTICS
   - OPEN DISCREPANCY LOG
     - READY FOR CLOSEOUT TEST
   - STATUS OF EACH DEFINED SYSTEM
   - RESPONSIBILITY LOG
     - INDIVIDUAL RESPONSIBILITY STATUS
3. UPDATE:
   - DAILY
   - WEEKLY - DISTRIBUTED AND REVIEWED
4. SCHEDULE:
   - SETUP LOGICAL SYSTEM TEST SEQUENCE
   - KEYED SCHEDULE STATUS TO DR'S
   - TRACK DR HISTORY

Figure 11. T-44 Job Accounting

## Auditing

The final audit process follows naturally from the HSI in that system testing proceeds into Government acceptance testing utilizing the Government-approved document. This occurs after in-house testing has reduced all significant discrepancies tc zero.

## CONCLUSIONS

The approach described herein provided never-before-attained management visibility into audit status. All parties were able to review detailed printouts as to the exact status of the project. Responsibilities were clear and it was obvious that the job was under control. The printouts proved to be extremely valuable when used as the basis for communications, both at in-house meetings and for the customer's review.

As a result of this experience, Gould, Inc., Simulation Systems Division Policy and Standards for "On-Line Software Configuration Management" have been developed and utilized on a number of projects with excellent results.

## Computer Printout Examples.

A typical example of one of our programs is shown in the following illustrations. Figure 12 summarizes the DR statistics by system. Figure 13 depicts the last page of the master software DR log. Figure 14 summarizes open DRs by responsible engineer. This printout is utilized at weekly meetings as a basis for review status. Figure 15 summarizes the DR statistics by responsible engineer.

## References


Bersoff, Edward H.; Henderson Vilas D.; and Siegal, St... CTEC Inc.; Software Configuration Management: A Tutorial

MIL-STD 1644 (1D), 7 March 1979, Trainer System Software Development


T44 DR STATISTICS

| SYSTEM | OPEN | TESTED | CLOSED | TOTAL |
|---|---|---|---|---|
| ENGINE START | 0 | 0 | 11 | 11 |
| GROUND DYNAMICS | 0 | 0 | 17 | 17 |
| ENGINE GROUND | 2 | 0 | 2 | 4 |
| ACCEL, TO, STOP & DECEL | 0 | 0 | 1 | 1 |
| FLIGHT INSTRUMENTS | 1 | 0 | 9 | 10 |
| WHEELS & BRAKES/CRASH | 0 | 0 | 4 | 4 |
| PROPS | 0 | 0 | 4 | 4 |
| ATMOSPHERICS/ROUGH AIR | 0 | 0 | 2 | 2 |
| ENGINE FLIGHT | 0 | 0 | 13 | 13 |
| STALL AND BUFFET | 0 | 0 | 1 | 1 |
| ELECTRICAL SYSTEM | 2 | 0 | 34 | 36 |
| FUEL SYSTEMS | 0 | 0 | 13 | 13 |
| GEAR & FLAPS | 0 | 0 | 16 | 16 |
| ANNUNCIATOR & FIRE SYSTEM | 0 | 0 | 0 | 0 |
| ECS & MISC SYSTEMS | 1 | 1 | 13 | 15 |
| HARDWARE | 23 | 0 | 126 | 149 |
| DRED | 1 | 0 | 10 | 11 |
| EXEC & DEBUG | 1 | 0 | 6 | 7 |
| CONTROL LOADING | 2 | 0 | 20 | 22 |
| INSTRUCTOR STATION | 23 | 1 | 80 | 104 |
| NAVIGATION | 4 | 1 | 26 | 31 |
| NAV RECEIVERS | 0 | 0 | 14 | 14 |
| MOTION | 2 | 0 | 10 | 12 |
| AUTOPILOT | 1 | 0 | 6 | 7 |
| FLIGHT & AERO | 3 | 0 | 23 | 26 |
| INPUT/OUTPUT | 4 | 0 | 11 | 15 |
| COMMUNICATIONS | 3 | 0 | 2 | 5 |
| AURAL CUE | 0 | 0 | 2 | 2 |
| PITCH ON GROUND | 0 | 0 | 0 | 0 |
| SURFACE VS CONTROL DEFLT | 0 | 0 | 0 | 0 |
| PROPELLER THRUST | 0 | 0 | 0 | 0 |
| CONTROL-FRICTION/INERTIA | 0 | 0 | 0 | 0 |
| TRIM | 2 | 0 | 0 | 2 |
| LONGITUDINAL STABILITY | 0 | 0 | 0 | 0 |
| LATERAL STABILITY | 0 | 0 | 0 | 0 |
| SPIRAL STABILITY | 0 | 0 | 0 | 0 |
| REPLAY | 0 | 0 | 1 | 1 |
| NCS-31 SELF TEST | 0 | 0 | 0 | 0 |
| ATP VERIFICATION | 0 | 0 | 0 | 0 |
| INSTRUMENTS | 9 | 0 | 5 | 14 |
| TOTALS | 84 | 3 | 482 | 569 |

Figure 12. T-44 DR Statistics for Each System

MASTER SOFTWARE DR LOG

| DR NUMBER | SYSTEM ......AFFECTED...... | RESP ENG | DATE .TESTED. | DATE .CLOSED. | DESCRIPTION ........................................ | STATUS | TAPE NO. |
|---|---|---|---|---|---|---|---|
| 561 | TRIM | DDD | | | ELEC TRIM - A250 BOMBS - #2 | | |
| 562 | HARDWARE | JR | 12/12/79 | 12/14/79 | #2 : SYS FRZ - FUEL FLOW GLITCH | CLOSED | |
| 563 | HARDWARE | JR | | | #1 : VEL PARM FRZ LITE OUT | | |
| 564 | HARDWARE | JR | 12/12/79 | 12/14/79 | #2 : WPT REMOTE UNIT SW IS BENT&LOOSE | CLOSED | |
| 565 | COMMUNICATIONS | TJD | | | LOWEST FREQ IS 225.00 | | |
| 566 | ELECTRICAL SYSTEM | TJD | | | DC PWR. - GS, PP, CP | | |
| 567 | INSTRUCTOR STATION | RA | | | GCA STATUS DISPLAY | | |
| 568 | INSTRUCTOR STATION | RA | | | XCY SPECIAL SYMBOLS | | |
| 569 | HARDWARE | JR | | | #2 : RUDDER PEDALS | | |

Figure 13. Master Software DR Log



RTM DR LOG

| DR NUMBER | SYSTEM ......AFFECTED...... | RESP ENG | DATE .TESTED. | DATE .CLOSED. | DESCRIPTION ........................................ | STATUS | TAPE NO. |
|---|---|---|---|---|---|---|---|
| 426 | FLIGHT INSTRUMENTS | RTM | | | MAX ALLOWABLE AIRSPEED @165 IS 172 | | |
| 441 | INPUT/OUTPUT | RTM | | | CPLT VSI OFF UP TO 50 FPM | | |
| 465 | NAVIGATION | RTM | | | IC5/APPR = IEFD | | |
| 466 | NAVIGATION | RTM | | | IC5/ICRP = X-CNTRY NOT APPR | | |
| 478 | EXEC & DEBUG | RTM | | | MUST CLEAN UP DISK | | |
| 556 | DRED | RTM | | | DRED TEST #7 NOT WORKING | | |
| 559 | INPUT/OUTPUT | RTM | | | RESET NOT DRIVING FD ATT/ADA | | |

Figure 14. Open DR Log Keyed to Responsible Engineer

| | | T44 DR STATISTICS | | | |
|---|---|---|---|---|---|
| ENGINEER | | OPEN | TESTED | CLOSED | TOTAL |
| | RTM | 7 | 0 | 36 | 43 |
| | JR | 26 | 0 | 135 | 161 |
| | TJD | 9 | 1 | 96 | 106 |
| | SD | 3 | 0 | 41 | 44 |
| | DDD | 5 | 0 | 19 | 24 |
| | TZ | 4 | 1 | 35 | 40 |
| | HD | 3 | 0 | 5 | 8 |
| | GL | 2 | 0 | 64 | 66 |
| | RA | 20 | 1 | 51 | 72 |
| | JM | 5 | 0 | 0 | 5 |
| TOTALS | | 84 | 3 | 482 | 569 |

Figure 15. T-44 DR Statistics by Responsible Engineer

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# SOFTWARE DEVELOPMENT FOR THE MULTI-ENVIRONMENT TRAINER (MET)

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ABSTRACT

The MET system is a tactical team trainer designed to simulate multiple-ship tactical operations. The functions being simulated span the under sea, surface, and air environments and include operations in the Bridge, Combat Information Center and Sonar areas. The MET training system is designed about the use of eight computers configured in two groups of four. Each group of four computers simulates the functions of a PCG (patrol craft gunboat) class ship.

The MET software development will result in the generation of approximately 150,000 computer instructions, a portion of which reside in each of the four computers which simulate tactical ship operations. Management control and technical development of the MET has been characterized by the development and adoption of meaningful software development practices and procedures and adherence to the fundamental concept that software design must precede coding.

## INTRODUCTION

### System Description

The MET system is a tactical team trainer designed to simulate multiple-ship tactical operations. The functions being simulated span the under sea, surface and air environments and include operations in the Bridge (ship control), Combat Information Center (air/surface search radar, electronic warfare and weapon fire control), and Sonar areas (Passive/Active sonar and torpedo fire control), see Figure 1.

The MET training system is designed about the use of eight computers (SEL 32/75) configured in two groups of four processors. Each group of four computers performs a set of dedicated functions, in real-time, which simulate the operation of a single PCG class ship. The various modes of trainer operation permit the execution of exercises involving either one or two ships. Data exchange among the eight computers is accomplished via a block of shared memory while access to required peripherals is controlled by a program directed peripheral switch, see Figure 2.

### Software Description

The MET software architecture is characterized by five subsystem areas: Master Control, Passive Sonar, Active Sonar, Radar and Off-Line Processes. The first four subsystem areas represent the real-time portion of the MET software which resides in each of the two sets of four MET computers. The remaining software, which does not execute in real-time, is referred to as the Off-Line Processes and includes such programs as Diagnostics, Daily Readiness Test, Data Base Generators, etc.

Execution of the MET software, resident in each processor, is directed by a simulation executive which operates under control of the Real-Time Monitor (RTM) operating system. Several aspects of MET software design contribute toward making the development of that software a challenge. To begin with, much of the MET software interacts with government furnished equipment (GFE), performing the tasks of stimulation and simulation. Secondly, a significant interplay exists between the various programs resident within a given processor or processors. Finally the values computed by all of the MET processors contribute to a large and reasonably complex system data base which must be accessable to all computers in a manner which permits the satisfaction of the system's real-time requirements.

### Development Concepts

Several concepts, basic to the development of software, were adopted and/or augmented for use on the MET project. These concepts were selected with an objective in mind of defining a set of procedures which could be utilized throughout the company for the development of future software systems. Each of these basic concepts is discussed briefly below.

Chief Programmer Team. The MET software organization utilizes the Chief Programmer methodology. A team of software engineers led by a chief programmer is responsible for the design, documentation, implementation and integration of each subsystem area of software development. Each of the chief programmers and several of the members of each subsystem team are continuously involved from the initial design phase through implementation and test and finally each team contributes one or two members to a software/system integration team.

Unit-Development Folder (UDF). A unit development folder is prepared for each unit of code developed and controlled using software configuration control procedures. On the MET project that unit is a Computer Program Module (CPM). The unit development folder serves as the central historical source of development information for a given CPM and the basis from which contract deliverable documents are prepared. The unit development folder contains:

FIGURE 1. MULTI-ENVIRONMENT TRAINER

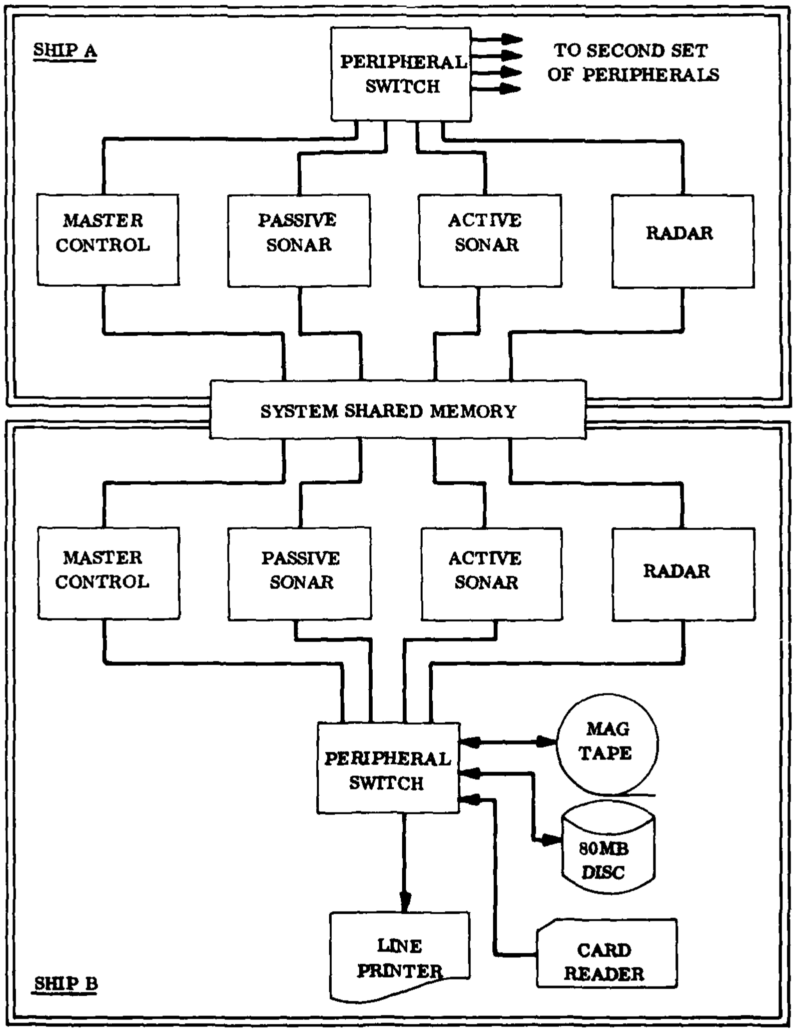


FIGURE 2. MET COMPUTER SYSTEM CONFIGURATION

1. Requirement Information - What the module is to perform as described in the contract specification, prepared in such a manner as to permit inclusion in the Program Performance Specification (PPS) document with little or no format modification.

2. Design Information - A description of the module design (control flow, data flow, inputs, output interaction with other CPMs), which is included in the Program Design Specification (PDS) document with little or no format change.

3. Detailed Design Description - A detailed implementation description which includes a flowchart and narrative for the CPM and each submodule or subroutine utilized by the CPM. The narrative is keyed to the flowchart by the use of labels which appear on both the flowchart and source code listing, insuring direct traceability from document to source listing.

The detailed CPM design description is prepared in a format which permits direct incorporation into the Program Description Document (PDD).

4. Unit-Test Plan - A description of the testing approach to be followed in debugging the CPM in question. The unit-test plan includes the overall approach to module testing and a description of each test case required to demonstrate the proper operation of each function performed by the module. All test case results are retained in the UDF for the CPM in question.

5. Problem Reports - Software problem reports, which document problems surfaced during the integration phase, are retained in the corresponding CPM unit development folder. These problem reports and their resolution provide a chronicle of the revisions undergone by the CPM in question.

A software problem report may also be prepared to document an enhancement or desired modification.

Top-Down Design. The MET software design was developed hierarchically from the top down by the development of a software work breakdown structure of five levels. These levels satisfy the objectives of grouping related functions and identifying units of code down to the lowest level controlled and beyond, if necessary. Figure 3 illustrates the structure of MET and of one of the MET software subsystems to the lowest level.

1. Computer Program (CP) - The CP level comprises the entire deliverable software product.

2. Computer Program Configuration Item (CPCI) - The CPCI is a major functional part of the computer program and may be of such a size or function as to be a separately deliverable and/or contracted item.

3. Computer Program Component (CPC) - The CPC is a subordinate functional part of the computer program which is usually grouped with other CPCs to form a CPCI.

4. Computer Program Module (CPM) - The CPM is the smallest functional unit identifed at the system software level and controlled by configuration management procedures. CPMs are grouped with other CPMs to form a CPC.

5. Computer Program Submodule (CPSM) - The CPSM identifies subroutines which are included within the CPM. Submodules are not controlled by configuration control procedures because any change to a submodule is considered a change to the parent CPM which is controlled.

Module Characteristics. The computer program module (CPM) definition adopted for the MET project is characterized as follows:

1. Must be less than 200 higher order language statements in length.

2. Must perform a well defined function.

3. Must lend itself to thorough testing.

4. Must be an aggregate of software to which specific system requirements can be traced.

5. Must permit changes without disturbing the overall software structure.

Higher Order Language. FORTRAN-77 was selected as the implementation language for MET. The selection was based on the fact that FORTRAN-77 includes the structured programming language constructs of IF, THEN, ELSE, DO UNTIL, DO WHILE, etc., which facilitate the generation of clear easy-to-follow code.

## Software Design Phase

The MET software design phase included those activities which resulted in the preparation of the contract deliverable documents, described below, and the conduct of both the Preliminary and Critical Design Reviews (PDR, CDR), see Figure 4.

Software Documents. Five basic software documents were prepared which define the system specifications, design and implementation . Each is described briefly below.

1. Program Performance Specification (PPS) - The PPS document is based upon an analysis of the contract specification and describes the functions to be performed by the system. This description includes the equations/algorithms which are to be implemented to simulate real-time functions and the performance characteristics/operational ranges of these functions. Data Input/Output diagrams are included to illustrate the flow of inputs to and outputs from the various system function modules.

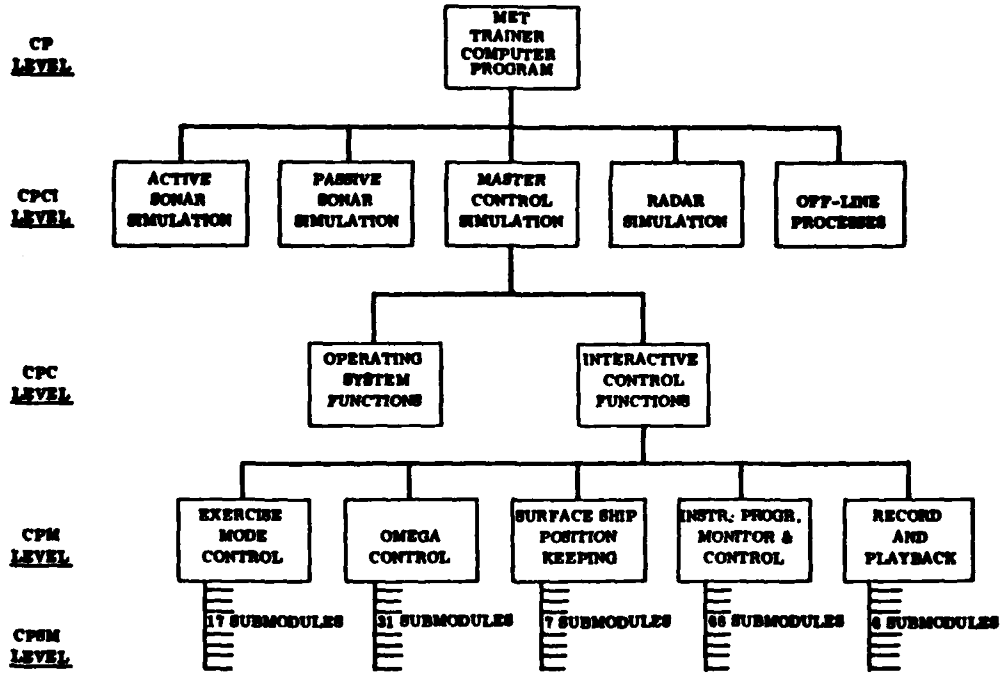


FIGURE 3. MET SOFTWARE WORK BREAKDOWN STRUCTURE

2. Interface Design Specification (IDS) - The IDS document is based upon the PPS, the contract specification and description of the system hardware. The IDS describes in detail the flow and content of signals and data messages passing between the digital compter processors which comprise the system being implemented.

3. Program Design Specification (PDS) - The PDS document is based upon the IDS, which defines the data interfaces between the digital processors in the system, and the PPS, which specifies all of the functions to be performed by the system. The PDS provides a description of how the system being designed will satisfy the performance requirements specified in the PPS. Included is a definition of the software architecture, the identification and description of each computer program module to be implemented, the inputs and outputs required and produced by each CPM, and diagrams which illustrate the flow of control and data between the CPMs of a subsystem.

4. Program Description Document (PDD) - Preparation of the PDD is based upon the three predecessor documents described above and includes a detailed definition of the implementation characteristics of each CPM in the system. The PDD constitutes a "code-to" level document and includes a logic flowchart of each CPM and CPSM in the system, accompanied by a narrative keyed to the flowchart, which describes the processing indicated. A summary of the data base items used/produced by each CPM and CPSM is included in tabular form to support the implementation description.

5. Data Base Design Document (DBDD) - The DBDD is developed in parallel with the PDD and includes a detailed definition and description of each data item stored in the system data base and accessed by the real-time system software. Included are the definitions of variables, constants, tables, indexes and flags. The combination of the PDD and DBDD documents provide the minimum required information needed to implement the system software.

Design Reviews. Two major design reviews were conducted on the MET project. Each is briefly discussed below.

1. Preliminary Design Review (PDR) - The PPS is the basic document subject to review during the PDR and, when approved, constitutes the allocated software baseline. The PPS, associated plans, and any technical and/or contractual issues are reviewed with the customer during the PDR to assess the adequacy of the system performance specification and software allocation, and to obtain a mutual commitment to proceed to the detail design phase.

2. Critical Design Reveiw (CDR) - The CDR is conducted following the preparation of the PDS and DBDD which constitute the software product baseline at the CPM level. The CDR is normally conducted as a series of formal briefings during which the software design is related to the specification requirements and described in sufficient detail

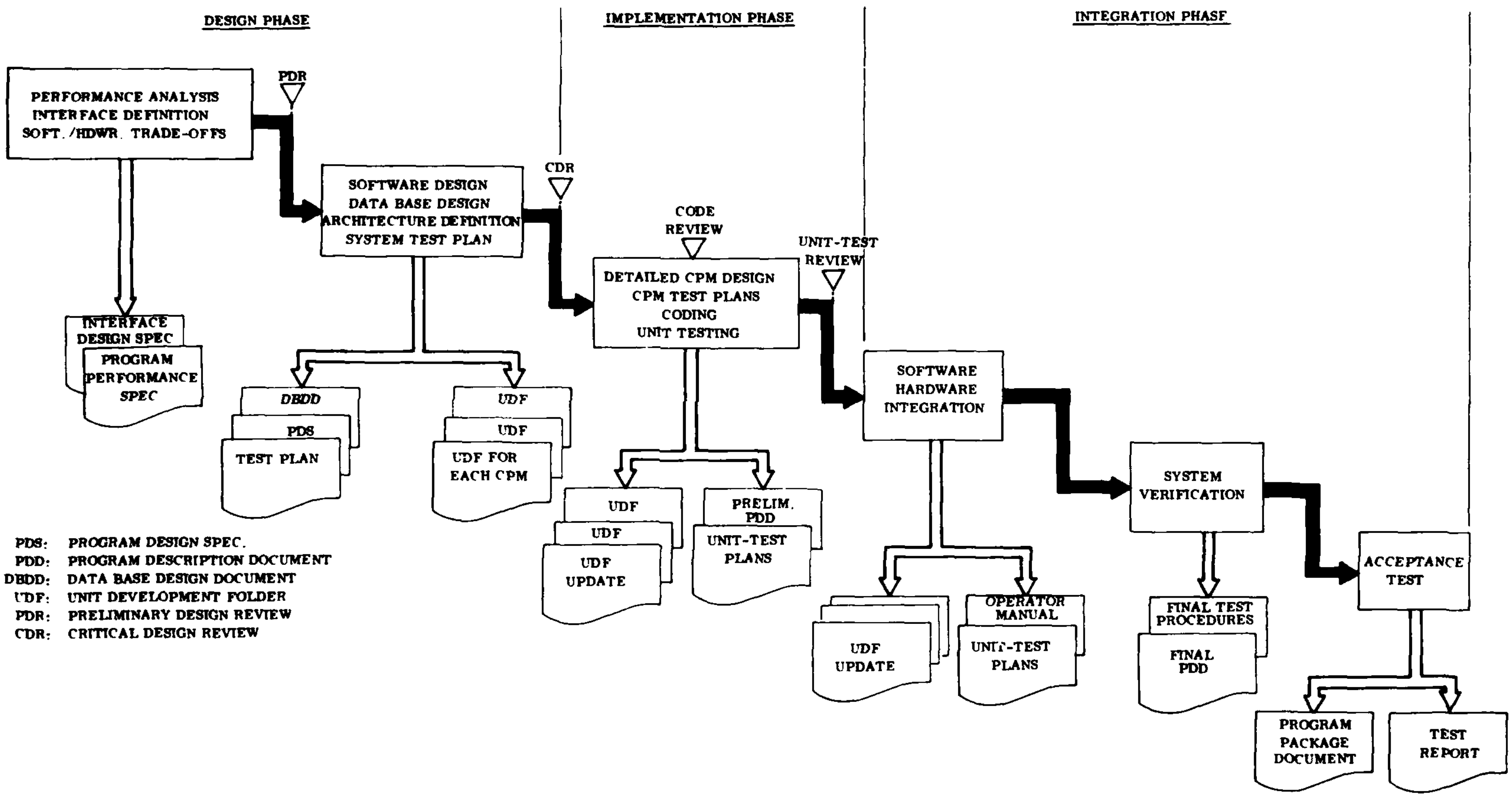


FIGURE 4. SOFTWARE DEVELOPMENT SEQUENCE

to demonstrate that all system requirements (processing, timing, simulation) are being satisfied by the software design. The CDR is performed to assess the adequacy of the software product design and to obtain an agreement among those participating to proceed to the software implementation phase.

Lessons Learned. A number of problems were encountered and resolved during the MET design phase which in fact have provided a valuable learning experience which hopefully will be applied to similar software developments in the future.

1. Standard Development Practices - Assembly of the MET software development team, as is typical with many large software development efforts, was an event which resulted in the joining together of a group of software engineers with varied experiences and backgrounds, many of which had never worked together. Each member of the team enriched the group with unique experiences; however, each such contribution was accompanied by personal operational predjudices which tended to insure that a different design and implementation approach would be followed in developing each module of code.

The fusion of individual viewpoints and the development of a unified approach to software development was accomplished by the preparation of a set of software development standards that were adopted and followed by all to both design and implement the MET software. These standards provided a basic, if not always consistent, set of rules to live by. All members of the team were encouraged to recommend refinements to these standards as the project proceeded from one phase to the next. Among the major development standards adopted are the following:

o Unit Development Folder for each CPM developed
o Data and Program Naming Conventions
o Flowcharting Standards
o Source Code Preface
o Code Indentation and Labeling
o Design Reviews
o Resource Estimation

Although the development standards adopted did not enjoy universal acceptance among all team members they did establish a level of consistent guidance. Whether accepted with enthusiasm or resignation, the standards placed everyone in the same circumstances. Despite the effort to standarize there were a number of heroic examples of deviation from the accepted rules; however, I believe that these were minimized by the existence of the standards.

2. Internal Design Reviews - Included in the development standards is a requirement for the performance of several types of product reviews, i.e., Design Review, Unit-Test Plan Review, Code Review and Unit-Test Review. The reviews are conducted at various stages of development and are briefly described below.

a) Design Review: Conducted during the preparation of the preliminary Program Description Document and consisting of a walkthrough, by the responsible software engineer, of the CPM flowchart with an attendant discussion of the CPM inputs, processing, outputs and interactions with other CPMs.

b) Unit-Test Plan Review: Usually performed at or near the end of code generation and consisting of an examination of the CPM unit-test plan for adequacy of CPM demonstration. All test cases are examined along with inputs and expected processing outputs.

c) Code Review: Conducted following code generation and consisting of a review of the code logic to insure compliance with the logic contained on the CPM flowchart and a review of the code comments to insure a direct correlation with the PDD flowchart narrative.

At the time of review, all flowchart corrections must be red-lined as well as the corresponding PDD narratives describing the flowchart.

d) Unit-Test Review: Performed at conclusion of CPM unit-testing (debugging) and consisting of a careful review of the CPM unit-test plan, all test cases, the inputs to those test cases and a comparison of the computed outputs with the anticipated outputs as documented in the test case descriptions. At the time of Unit-Test Reveiw all software documents (PPS, PDS, PDD and DBDD) must have been corrected (red-lined) to reflect the unit-tested program.

The completion of unit-test plan, code, code review, unit-testing and unit-test reviews were events which were monitored formally on a weekly basis. Considerable management attention was given to these reviews to insure that each CPM was thoroughly tested prior to being released to the integration team for integration into the system and to insure that the "as coded" CPM was properly documented hence minimizing the need for a crash documentation update cycle at project end.

3. Document Preparation - The preparation of software documents in accordance with the SECNAVINST 3560.1 and Mil Std 1644 documentation standards was a more formidable task than had been projected. The serial manner in which the documents were required by the contract schedule guaranteed that differences and inconsistencies would exist in each succeeding document. On the average the time scheduled between the PPS, PDS, PDD and DBDD documents was approximately three months.

During each succeeding document preparation period a better understanding of system operation and design was obtained. As this more complete system understanding found its way into the document being generated, differences between the new document and the previous document(s) were created.

This condition was the source of numerous difficulties with customer personnel who were reviewing the documents for consistency and traceability. The end result of this situation was that a major document update was performed to bring all the software documents to the same level of design, an activity which seriously impacted the start of implementation.

The problem of discrepancies between documents generated serially on a tight schedule would have been practically eliminated if a period of time had been incorporated in the schedule at the time of each document's completion during which the previous document(s) could have been updated to the design level of the most recent document.

Software Implementation Phase

The MET software implementation phase included those activities which resulted in the generation of code, the procedures for testing that code and the conduct of reviews to insure a software product that performed the functions for which it was designed, see Figure 4. The implementation sequence followed in the MET system was: development of a unit-test plan; code generation; code review; unit-test; and unit-test review.

Unit-Test Plan. A unit-test plan was prepared for each CPM implemented in the MET system. The unit-test plan described the approach to be followed in testing a CPM and included a description of each test-case required to demonstrate the proper operation of each function performed by a CPM. Each test case description included the inputs used in the test and the projected outputs to be computed. Normally the unit-test plan was developed in parallel with the generation of code for a CPM.

Code Generation and Review. MET code was written using the FORTRAN-77 language and the coding standards adopted at the start of the project. Only certain time-critical CPMs were coded in assembly language. Review of the code required a "clean compile", not a debugged or unit-tested program. Code Reveiw was performed by the chief programmer under whose direction the CPM was being developed. Review consisted of an examination of the code to insure:

a) Compliance with the coding standards

b) Correlation between the code logic and the CPM flowchart logic

c) Correlation between the code comments and the flowchart narrative (PDD)

d) Corrected (red-lined) CPM flowchart and narrative to reflect the "as coded" state of the CPM.

Unit-Test and Review. The Unit-Test activity consisted of debugging a CPM in accordance with the unit-test plan and its test cases. The output results of each test case were saved for the unit-test review. CPM unit-testing is normally accomplished in a static environment, i.e., non real-time, one CPM at a time. A number of test tools were developed for use on the MET project which facilitated the execution and test of a CPM(s) in both the static and dynamic environmments.

When a programmer felt that a CPM was completely operational, a unit-test review was held. This review was performed by a group of concerned software engineers which included all of the chief programmers. In attendance also were other programmers whose CPMs might interact with the CPM being reviewed.

The responsible programmer presented the CPM design, the unit-test plan, a discussion of the test cases run and provided all of the test case outputs for examination by the review team. Any problems surfaced in the course of the review were documented by the attending software quality management person and a schedule established for the resolution of those problems.

Following successful conclusion of a unit-test review, a CPM was considered ready for advance to the integration phase. From this point on the CPM source code was controlled by the software librarian.

Lessons Learned. The software implementation phase was highlighted not only by the traditional difficulties of monitoring status but also by a few pleasant surprises as described below.

1. Code Generation - The MET implementation phase was preceded by a design phase which was characterized by the preparation of software documentation (PPS, PDS, PDD, DBDD). The generation of these documents, which culminated in a preliminary "code-to level" PDD, produced a software design that had been thought through. As a result, the code generation was accomplished much more rapidly than anticipated.

2. Unit-Test Plan - It was determined that development of a CPM unit-test plan was accomplished most effectively when generated in parallel with or following actual code generation. When developed prior to code generation, more time was required to produce the unit-test plan and invariably it had to be modified slightly after CPM coding.

3. Unit-Testing - The use of the Program Module Test (PMT) facility, for unit-testing of individual modules, was felt to be quite effective. PMT is a test tool which accepts testing commands, in card format, which result in initial values being set, a CPM being brought into execution a specified number of times and selected register and/or memory locations being printed as the CPM is executed. An additional value of PMT was that the test card deck could be used over and over as changes were made to a CPM's code, hence, keeping the testing base constant.

Other software test tools were developed which permitted the testing of several CPMs in parallel in a dynamic or real-time environment.

4. Implementation Status - A number of methods were used to assess implementation progress. Several are discussed below.

a) PERT Type Charts - This type of chart is a widely accepted management visual; however, it can be quite difficult to interpret. The MET software PERT type charts were color-coded with black, meaning a task or activity accomplished, red, meaning not done and behind schedule and green, for done and ahead of schedule. On more than one occasion task performance sequence was changed because certain routines became more critical than others, hence, were started out of the planned sequence. Whenever this situation occurs the software manager is faced with having to explain that the presence on the chart of incomplete tasks (red) is unimportant to the overall schedule or that the red is balanced by the presence of tasks completed early (green). The effort required to explain this type chart, and put the program manager at ease, can often be greater than that required to manage the development itself.

b) Progress Graphs - A number of graphs were prepared and updated on a weekly basis which plotted actual accomplishment against the plan. For example a graph was generated for the completion of each software development event, i.e, Unit-Test Plan, Coding, Code Review, Unit-Test and Unit-Test Review. Plotting of the actual event completions against planned completions showed very clearly when and if the implementation activity was ahead of schedule or behind. These graphs were used quite effectively to provide progress status to management as well as the developers themselves.

c) Status Meetings - Maintaining individual motivation on a software development project of long duration which is frequently beset by deadlines is a diplomatic and management challenge of some proportion. On MET it has been accomplished by holding weekly software status meetings with all of the members of a team in attendance. Status is obtained by reviewing each item due that week and determining if the item is complete, if not, why not, and when necessary establishing a new promise date for that item.

Quite obviously this type of inquiry places each individual in the limelight which, on occasion, is uncomfortable. Initially the status meetings were not very popular and were the source of considerable grumbling associated with unrealistic schedule dates, inoperative hardware, unavailable information which impacted task completion, etc. However, after the first six or seven meetings a marked change in attitude became apparent. Individual engineers who had been given the opportunity to modify schedule dates now took them much more seriously. Meeting the completion dates estimated became a matter of professional pride.

The weekly status meetings provided a forum where management could applaud individual and team performance to the schedule and where problems, which impacted software development, could be aired and resolved. The overall effect of the status meetings on team motivation was quite positive.

## Software Integration Phase

The software integration phase included those activities which resulted in assembling all of the software components into subsystems, exercising the functions of each subsystem independently, isolating and resolving processing anomalies, exercising all subsystems in parallel and producing a total system which operates properly with the hardware base, performing all of the functions for which the system was designed. The procedures followed to control software/system integration are briefly described below.

Integration Team. Integration of the software CPMs into an operational system is an activity which is performed by an integration team. The integration team is composed of two or three of the most knowledgeable people from each subsystem area. The team is responsible for development of an integration plan, the generation of unit-test plan procedures, describing how the various system functions are to be exercised, and for the actual execution of those procedures.

It must be noted here that a considerable effort was expended during the implementation phase to insure that each CPM had been extensively unit-tested. Each CPM underwent a thorough unit-test review where computed output was verified, hence, every attempt was made to insure that each CPM was an operational package prior to the integration of that CPM into the system. Hopefully the precautions taken will minimize the integration effort required.

Integration will be carried out on various levels from the verification of single-thread system functions, with or without program stubs, to mulitple processes operating in parallel in real-time. Unit-test plans are generated for each level of system testing.

Software Problem Reports. As may be expected, software problems will be surfaced in the course of integrating the system. These problems will be documented on Software Problem Report forms by the integration team members and monitored by the software Quality/Management (Q/M) person. The problems identified during integration may be assigned to the original programmer for resolution, if still available, or they will be resolved by the integration team directly.

As resolutions are implemented the software Q/M person will be involved to verify that the change has been made and to record the need for documentation modifications as required.

Configuration Control. At the conclusion of CPM implementation (successful completion of the unit-test review), a CPM is considered to be thoroughly debugged and to perform in accordance with the documented design. One of the requirements of the unit-test review is for the responsible programmer to turn over the CPM source and object code to the Software Librarian who obtains a revision number for the CPM from the software Q/M person, and records it in the system library where it becomes available to the integration team for incorporation into the system.

Control of CPM source and object code will be maintained by the software Q/M person and the software librarian throughout the integration period. Any and all modifications to be incorporated into a CPM will be made by the software librarian to the CPM source which is then recompiled, has a new revision number assigned, and is re-recorded in the system library for use by the integration team. This control procedure eliminates surprise nocturnal fixes made by programmers to CPMs which are actively being integrated.

Lessons Learned. At the time of this writing, integration of the MET software system has not yet been initiated, hence, it is premature to discuss integration advantages which may be realized. It is believed, however, that the integration should go more smoothly based upon the extensive design documentation prepared in advance of implementation, and of the thorough unit-testing performed and verified for each CPM prior to submission for integration.

## SUMMARY

Management control and technical development of the MET software has been characterized by the development and adoption of meaningful software development practices and procedures, and adherence to the concept that software design must precede implementation. This activity has provided valuable learning experiences in a number of areas, some of which are outlined below. Inasmuch as the project has not entered into the integration phase, comments are confined to the design and implementation phases of MET development.

### Design Documentation

The military standards required and utilized on the MET project (SECNAVINST 3560.1 and Mil STd 1644) have required much more time and manpower to satisfy than was originally planned.

Adherence to these standards, however, does impose a discipline, namely, that one must have considered the design thoroughly if it is to be described in the detail required by these standards. This is an investment which has begun to pay off in the software implementation phase and hopefully will continue to pay off during integration.

An attempt should be made at project initiation to incorporate sufficient schedule time between each document generation to permit updating previous documents to the same level of design. If this is not possible it should be understood and accepted that differences and inconsistencies will exist in the set of documents produced.

### Software Standard Practices

It is absolutely necessary that a fairly rigid set of software development practices be available if there is to be any hope of molding a professional team that will be moving in the same direction toward a common system goal.

Although somewhat restrictive of individual professional styles, the standards enforce a consistency which on a sizeable project is often more valuable than individualism. The standards themselves must be subject to continual refinement by recommendation from any member of the software staff. People identify with a set of standards that they can help to formulate.

### Software Implementation

As a result of the requirement for design documentation prior to implementation and the establishment of standards, the generation of code has occurred much more rapidly than anticipated.

The design errors surfaced in the course of code generation have also tended to be more minor than in previous projects.

Unit-testing (debugging) of individual CPMs appears to be progressing more quickly than anticipated for the same reasons.

### Development Team Motivation

The experience gained on the MET project indicates that the most effective way to maintain a high level of team motivation is to monitor performance regularly. Weekly status meetings were the vehicle utilized on MET.

Performance monitoring using this methodology provides a technique for surfacing problems which, upon verbalization, may be shared by a number of team members. Obviously if a problem is not surfaced it cannot be solved. Status meetings were extremely helpful in this regard.

Each item reviewed in the status meeting was subject to schedule modification, if the conditions so required, a situation which enabled a team member to reflect a sense of realism and personal commitment in the development plan.

The status meetings, which were held weekly during the implementation phase, provided management with an opportunity to display an interest in what team members were doing and to recognize individual and team achievements.

The result of the status meetings was plotted on five graphs depicting progress versus plan for each of the primary implementation activities (Coding, Unit-Test Plan, Code Review, Unit-Test, Unit-Test Review). These graphs were prominently displayed for all to assess their progress.

Another factor which has played no small part in maintaining positive team motivation has been an involved, knowledgeable customer. The MET trainer is being developed by the CUBIC Corporation for the Naval Training Equipment Center (NTEC) Orlando, Florida. NTEC personnel have been personally involved with the MET design and software developments and have spent many hours reviewing both the design and implementation documents at the CPM and CPSM level. Their participation in the MET development has contributed to a sound technical relationship, with each of the chief programmer teams, and has resulted in a continued and productive dialog between developer and customer.

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# SOFTWARE QUALITY ASSURANCE APPLIED TO TRAINER SYSTEM DEVELOPMENT

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ABSTRACT

This paper will discuss the application of software quality assurance techniques to trainer software development, taking into consideration military standards and specifications and the unique characteristics of trainer development programs. Because military customers are paying greater attention to software development and software documentation, software quality assurance has become an increasingly important management objective. Although there are no quick recipes for adapting software quality assurance techniques and standards to trainer development, this objective can be met by analyzing the software specifications and standards along with the software quality assurance specifications and standards, by considering the unique aspects of trainer development, and by considering the aspects of applying and adapting software standards to trainer development. First, the various specifications and standards that apply to software development must be analyzed with particular attention paid to their interrelationships and to their relationships with deliverable data items. Then, this conceptual framework must be related to the software quality assurance standards and specifications. Differences and similarities between the standards and specifications written by different military customers will also be considered. Given this overall picture of the requirements for software development and quality assurance, the unique aspects of trainer development may be considered. Among these are shortened schedules, abbreviated data requirements and the application of weapon system standards to trainer development. Once the various requirements and the peculiar constraints of trainer development have been analyzed, the next step is to consider the meaningful application of software standards and quality assurance techniques to trainers. Among these considerations are cost effectiveness, who should accomplish the various quality assurance tasks, applicability of internal standards, whether tasks are best handled on a company or program basis, tailoring quality assurance functions to program needs, and the problem of assuring quality of software when there are no specific software data item requirements. In conclusion, this paper will present an approach to developing a software quality assurance program for trainer system development.

Software management and control presents the same challenge to the trainer industry that it does to major computer and weapons system manufacturers. Although the overall development cost for a training system may be only a fraction of the cost for the system it simulates, the percentage of development cost allocated to software may be greater in the training system because the trainer industry has become increasingly software intensive and there is every indication that this trend will continue. Given the fact that the cost of software development comprises a larger portion of the cost of system development each year, controlling software development has become a primary management concern.

Methods and procedures for control of cost and quality of hardware development have been applied in industry for so long that they have become almost second nature and we no longer ask whether or not procedures such as an engineering drawing system or a hardware change control system should be instituted. Now that control of software development has become more of a concern, we cannot treat the software portion of system development as a black box design for which we dedicate money and manpower at the beginning of a program, only to have it slip from view until test and integration when it either works or does not work. But it is obvious that the same controls that have been applied to hardware development cannot be applied directly to software development and also that controls applied to major system software development might not be feasible or cost effective when applied to trainer system software development.

Control of software development is generally divided into management functions and quality assurance functions. Software management includes functions intended to specify and control the design, and software QA includes functions intended to monitor the design process according to the management objectives. A number of software management and QA techniques and procedures have been developed which can provide models for trainer software management and QA, and provide techniques that may be adapted to fit the needs of a trainer development program. Since the government is the major buyer and user of software, it stands to reason that the control of software design would be a major government concern. This concern is reflected in military standards and specifications, which include a rather complete blueprint for software development. It should be noted that the software management and QA techniques employed by many individual companies are either derived from or reflected in these standards. This is not to say that the military standards are the last word in software development or that they are unilaterally complete or effective, but they are a useful source for companies desiring to institute software management and control techniques and an effective software QA effort.

The military standards that describe the software development effort are MIL-STD-483, MIL-STD-490 and MIL-STD-1521, and documents which are devoted primarily to software QA are MIL-S-52779, MIL-STD-1679 and MIL-STD-1644. Briefly, MIL-STD-483 can be seen as the grandfather of this group of documents because it details the content requirements for software documentation along with MIL-STD-490. MIL-STD-1521 specifies the documentation required at the completion of the various phases of software development. MIL-S-52779 calls for the implementation of a software QA program and could be described as a parallel document of MIL-Q-9858, which specifies quality control requirements for hardware development. MIL-STD-1679, a Navy document, includes more detailed software quality program requirements and references a set of software documentation which is similar to that described by MIL-STD-483. Finally, MIL-STD-1644 is basically a MIL-STD-1679 approach applied to trainers with very little tailoring.

Two basic concepts are common to all of these documents and these two concepts can be applied to form the basis for a trainer software management and QA effort. The first of these is the concept of development phases. That is, the software development process is divided into successive phases marked by milestones, at which the design up to that point is analyzed and validated. The second concept comes into play in the form of documentation. Each milestone is represented by a documentation set which may consist of a specification or flow charts or printouts, depending upon the particular phase that is represented. This documentation must be seen as a management tool which provides visibility of the design and which provides sufficient detail to validate the design. The documentation also specifies what will be accomplished in the next phase so that at the completion of each phase, the documentation may be validated by comparing it with the documentation generated in the previous phase. This provides for traceability of the design to the original system requirements throughout all phases of development. A simplified schedule for a typical software development effort is shown in Figure 1.

For the purposes of this discussion, the software development process will be divided into four major phases: Analysis, Design, Coding, and Test and Integration. Other divisions are possible, provided each phase leads to a milestone which can be seen as a design baseline represented by a specific set of documentation that describes the design up to that point. The terms used to describe the documentation will be taken from MIL-STD-483, recognizing that the MIL-STD-1679 differs primarily in form, rather than intent.

If we envision a software development effort beginning with a decision to allocate funds to a certain project or beginning with a contract award, the first task is to analyze the system software requirements for testability, functional grouping, and implementation. Testability is a determination of whether or not the system requirements can be implemented and tested, because once the design is complete we must be able to prove that all system requirements have been met. Also during the Analysis phase, the system requirements might be divided into two or more functional areas, often called Computer Program Configuration Items, if it appears smaller units of design may be easier to control than one larger system. The major activity of this phase is the translation of system requirements into software requirements. That is, we analyze the overall requirements and come up with a set of instructions that can be understood and followed by a software designer. These instructions are contained in a Computer Design Specification, or a similar document, for each Computer Program Configuration Item. This document will include such information as block diagrams, general flow diagrams, interface definitions, and software system requirements. Often the milestone which closes the Analysis phase is the Preliminary Design Review, during which the Computer Program Design Specifications are compared to the overall system requirements and all necessary changes are incorporated.

During the Design phase, the software designers follow the requirements of the design specification and draft the Computer Program Product Specification. Among the activities in this phase are the preparation of detailed flow charts, developing a top-down module structure, and allocating the available time and memory. This phase culminates in a Critical Design Review during which the Computer Program Product Specifications are compared to the design specifications and validated, once all changes are made. The Computer Program Product Specification is a draft document at this point because it will be updated to include listings once the Coding and Test phases are complete.

Following the Critical Design Review, the product specifications may be turned over to the programmers for coding. Completion of this effort results in a milestone review which may take the form of a design review or a similar activity, such as a code walk-through. The purpose of this milestone is to check the code against the approved flow charts contained in the product specification before the code is entered into the computer load. This may be done on a module by module basis or in larger units. The documents that describe this milestone are the product specifications, which are updated to include the approved code.

A parallel branch of the development effort which has not been mentioned so far is the development of test plans, test procedures and test software. During the Analysis phase a plan to test the completed software should be established and the necessary procedures written. Any test and analysis software that will be required to verify system requirements should be designed and documented in the same way that the rest of the system software is designed. That is, test software should not be a last minute consideration. It may be helpful to allocate a Computer Program Configuration Item to the test software during the Analysis phase to ensure that it will be ready and operable when testing begins. Test plans and procedures should include provisions to test every requirement of the system specification.

The Test and Integration phase usually begins with some form of module testing. Modules may be verified against the design and product specifications according to the approved test plan and procedures. Verified modules are compiled into their respective Computer Program Components and further testing is conducted to verify the entire component before it is compiled into the Computer Program Configuration Item. The complete configuration item may then be validated against the design and product specifications. Once we have verified the software load, integration with the hardware may take place, and this process culminates in a testing procedure which validates the entire system against the system specification. Following successful completion of all testing, the updated product specifications define the production baseline for the computer program system.

So, we began with the system specification, gleaned from that document the software objectives, defined specific software design tasks, divided the design effort into phases that correspond to visible baselines, which were themselves defined by a specific set of documentation, and then compiled the software packages into a complete system which we verified against the system specification.

The objective of the software QA effort is to monitor this process and ensure that the system requirements will be met. Again using the military specifications and standards as a model, the software QA program tasks will include documentation reviews, participation in design reviews and walk-throughs, independent audits of design procedures, corrective action and trend analysis, and configuration control. Included in the configuration control tasks are monitoring of library controls, review of test reports, and change control.

In general, there are four design characteristics that the software QA representatives will hope to identify during the QA reviews and audits. The first of these characteristics is traceability of design requirements, which means simply that at each milestone of the design process, we should be able to trace each element in the software documentation back through the product specification and the design specification to the system requirements. If the documentation has been completed correctly and if the design has been documented completely, management confidence in the progress of the design will be gained from the reviews and audits. If design traceability has been lost, this problem will be evident in reviews and audits and there will be less confidence that the design will eventually meet all system requirements. Secondly, the various QA reviews and audits will determine whether or not all interfaces between software elements and between software and hardware have been identified and properly defined. Again, this is a major QA concern because if interface definition is ignored in the Analysis and Design phases of the development effort, there may be difficulties when we try to compile and test the software. The third consideration is to ensure that the design is proceeding according to the baselines established at the previous development milestone. That is, we check the design specifications against the system requirements, the product specification against the design specification, and the coding against the product specification. Finally, the reviews and audits will also ensure that the documentation conforms to the established standards for format and content.

The QA tasks and the development process we have briefly outlined in this paper are intended primarily for large scale design efforts and must be tailored to meet the specific problems often encountered in trainer system design efforts. Characteristic problems of trainer system development are shortened schedules, associated data requirements, and the application of specifications more suitable to development of critical systems or larger systems than to development of trainer systems. Managers and engineers experienced in trainer design may have asked questions similar to these: How can we write design specifications before the preliminary design review when it is scheduled two months after contract award? Is it cost effective to write design specifications if they are not required by the contract? How much of the software control exercised for critical systems is cost effective when applied to trainers?

Often trainer development schedules are shortened, especially when the trainer is intended to support a new device, because trainer design cannot begin until the device itself is designed because essential design data must be available, but the customer wants the trainer delivered in time to support training of personnel to use the new device. The optimum amount of time required to design a trainer is therefore squeezed into a shorter time frame. If schedules become shortened to the extent that tasks essential to the software design process may be limited or deleted, the impact on cost and delivery must be assessed. For example, a suggestion to skip the writing of design specifications or to eliminate module testing must be evaluated against the cost which may be incurred because traceability of the design was lost or some critical modules were poorly designed and not checked. Conversely, the cost and schedule risk of having to redesign software during customer acceptance testing may justify allowing more time at the beginning of the program to complete all design phases and QA tasks. It should be a function of the Analysis phase to determine whether contract requirements are consistent with schedule constraints, and, if there are conflicts, resolve them with the customer early in the program. A more risky approach would be to begin software development, that is, requirement analysis and the writing of design specifications, prior to contract award. In any case, if schedule brevity is a problem, it must be addressed to ensure that the software will be designed correctly and on schedule. In general, software design tasks and software QA tasks should not be eliminated because design deficiencies that are not discovered early in the design process are more costly to correct during the test phase.

Another problem which might be unique to trainer system development is abbreviated data requirements. What is meant by this is that the customer often does not order a complete set of software documentation or will specify documentation that attempts to combine two or more functions into a single document. An example of the first case is a contract which requires Computer Program Product Specifications but does not require design specifications. Or, rather than ordering both design and product specifications, the customer may order a document that combines the design and product specifications into one specification. In either instance, what might have been an attempt to save money by ordering one less document does not save the trainer developer a penny. The reason for this is that to develop reliable software, the trainer system contractor to write both specifications. For example, if a contract calls only for final documentation, the management and QA objectives which are dependent on the visiblity provided by design documentation will be difficult, if not impossible, to meet. Rather than risk losing control of the software design, the contractor will develop some means of assuring the quality of the design and often this concern will result in some form of preliminary documentation which can be used to evaluate the design before it is released to programmers and finally to coding. This implies, of course, that in these instances the contractor will generate documentation for which he will not be directly paid. The alternative approach would be the "big bang" theory whereby the design is minimumly controlled, if at all, and the entire software system is loaded and debugged during the test phase and the final documentation is generated sometime later. Although this seems to be a relatively inexpensive approach compared to writing specifications or similar documents according to defined design milestones, studies have shown that this is not the case. In fact, it has been concern over the high cost of test and integration that has led many companies to develop software management and QA procedures that emphasize maintaining control and visibility of the software during the entire design process.

Instead of leaving the question of software QA to the discretion of the manufacturer, the trainer customer might decide to impose software QA requirements. Often, however, the requirements imposed on the training system will be taken directly from the requirements imposed on the device that the trainer will be designed to simulate. This may result in what could be termed a software QA overkill. For example, the customer might desire a training system that corresponds to a new fighter aircraft, which, because of the criticality of the system, production concerns, and perhaps the handling of classified data, was developed under very strict software management guidelines. Usually, these take the form of more documentation, more design milestones, more testing, and more record keeping. The training system, however, will probably be designed to operate in a classroom environment rather than at supersonic speeds in the upper atmosphere, will involve a much lower production run, and will process a smaller amount of classified data, if it processes any at all. To impose weapon system standards on the training system would not seem to be cost effective in this case, and could result in a situation where the cost of control exceeds the cost of the software itself. What is needed in instances such as these is a careful analysis of the cost and objectives of the software system to determine the level of control necessary to ensure that management concerns will be satisfied through all phases of system development. Hopefully, a dialogue between the contractor and the buyer will result in an approach that balances software QA cost and software performance for a given training system.

It is clear from our discussion of some of the problems encountered in training system development that software management and QA programs and techniques proven in other areas of industry must often be tailored to meet the needs of trainer manufacturers. One way to approach the question of software management and QA from a company standpoint would be to come up with a suitable in-house program. In other words, rather than simply responding to whatever software management and QA requirements are imposed by prospective buyers, the trainer contractor could develop an in-house program that fulfills the objectives of software management. The advantage of this approach is that once the in-house software management and QA programs are off the ground, unique customer requirements may only imply a tweaking of the working system rather than the writing of wholly new company procedures. Also, if the company program is structured to meet the intent of military software standards, the contractor will probably not have to revise any of the internal procedures to meet the software management and QA program requirements of most military and commercial customers.

Assuming a decision is made to go ahead with developing company software management and QA programs, there are a number of considerations which must be addressed according to peculiarities of each company and its respective business. Among these considerations are what existing model can provide the basis for the company programs, how much control should be exercised, who should be assigned to the various tasks, and whether software management and QA should be handled on a company-wide or program by program basis.

As we have already implied in this discussion, the existing military standards and specifications probably provide the best model for developing software management and QA programs because they have already been applied in many areas of industry and because by applying such a model, we could satisfy both military and commercial customers. Since much of the instructive literature on the subject of software management and QA addresses the two part specification approach as a management tool and the guidelins of MIL-S-52779 as a QA model, if a company decides to use this approach or a derivative approach, there are plenty of helpful hints available. Such an approach is also consistent with the spirit of standardization because if all contractors developed unique methods of software design and documentation, communication would be difficult.

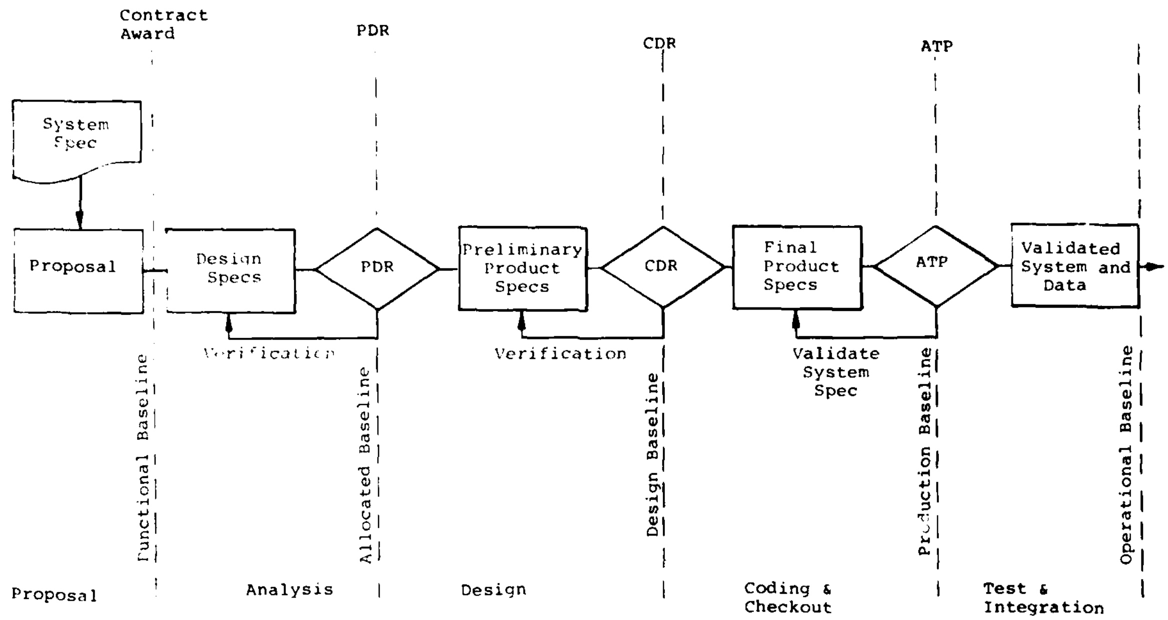
Also, it is much easier to explain your approach to a customer if it sounds familiar than if it is a unique system. Another source for software management and QA models would be the systems employed by other industries, of which there are also numerous published descriptions. In many cases, however, the titles used to describe the various design phases and milestone documents vary, but the general concepts of software management are very similar and resemble the military model.

Whatever model is chosen, a decision must be made to determine how much control should be exercised given the cost of control and the level of performance desired. In general, the software development procedures must provide enough visibility of the design that the software QA reviews and audits can be accomplished. Requirement traceability, interface definition, configuration control, and documentation standards are elements which should be part of any software management program and, as a minimum, the software QA program should include sufficient reviews and audits to ensure that these elements are present in each design. Documentation reviews can be used to check traceability, make sure that all interfaces are defined, and verify that the design is complete. Participation of the software QA representative in design reviews will provide an opportunity for questioning unclear aspects of the design. Software library controls and periodic audits of test reports and software change notice incorporaton can be used to verify that configuration control is maintained. Since it may not be feasible to review each software document in detail, sampling inspections may be planned to ensure that the established design procedures are being followed. Reviews of corrective action and analysis of error trends are useful in that they provide a basis for determining the effectiveness of software management efforts and recommending changes to standard procedures. Trend analysis, especially if a dollar figure can be applied, can prove valuable for the software QA effort because the effectiveness of such a program would then be expressed in dollars saved. This analysis could also show how well or how poorly the company software management procedures compare to published studies.

While making a determination of how much control should be exercised, it might become evident that we already have more control of software development than we realize. For example, we could have determined that the software design effort was out of control because no documentation requirements existed in the company, but found that most of the designers kept some form of notebook anyway. This would not be an optimum situation from a management or software quality point of view, but it is better than if nothing was written down at all. Perhaps the lead engineers had taken it upon themselves to insist that all designers keep notebooks and thus filled a void they recognized. What we are implying here is that all software QA functions do not necessarily have to be accomplished by dedicated QA personnel as long as all the necessary functions are assigned to someone. In many companies a software QA department has been created and staffed with software QA experts, while in other companies certain tasks are left entirely to other departments, such as engineering or configuration management, or assigned to other departments and then monitored by the software QA representatives. Library controls, for example, might be the responsibility of the software engineering department but subjected to periodic QA audits. Or, all configuration management functions, such as software change control, might be assigned to a separate department entirely and this department would also be responsible for configuration reviews and audits. It should be pointed out that MIL-S-52779 does not specify that all QA functions be performed by a QA department, provided all functions are performed.

Whether software QA functions are performed on a company-wide or a program by program basis is also left to the discretion of the contractor. This determination depends in part upon how much control is desired for systems that have no software QA or management requirements imposed by the customer. Generally, it would seem desirable to have a standard set of procedures to fall back on if none were imposed. Some of the functions, however, could be handled on a program by program basis if this approach seemed most cost effective. For example, rather than establishing a central library for the entire company, individual software libraries could be controlled by each program office. In this case we would have a company procedure which would assign responsibility for library control to the program offices. The same could be done for all other software QA functions and there could even be a person assigned to all these tasks from within the program office. Of course, during schedule squeezes, the loyalty of the QA representative to the program office might compromise the objectives we set out to accomplish. For every function assigned outside the QA department, there is a corresponding risk that the individual performing a quality task is likely to please whoever signs his paycheck, whether it be QA or the program office. Whatever approach is decided upon, it is important that it be documented in a set of established procedures so that all personnel involved in the software development effort will know their assigned responsiblities.

Obviously, there are no solutions which will work for all companies across all training system development projects. It is up to each manufacturer to address the question of software management and QA by taking into account the specific problems of the trainer industry and the unique management objectives within the company. The existing military standards and specifications provide a model which can be analyzed and tailored to meet the needs of a company program. Perhaps, once software control has been addressed on a company by company basis, a set of software standards applicable to the trainer industry, coordinated and approved by all industry representatives, might be written. This would provide the final solution to most of the questions addressed by this paper.




SOFTWARE DEVELOPMENT SCHEDULE

FIGURE 1

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SOFTWARE-INTENSE TRAINERS:

A STEP FORWARD IN AUTOMATED SOFTWARE SUPPORT

by

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ABSTRACT

A Software Support Facility (SSF) designed initially for the A-6E Weapon System Trainer (WST) and located at the Naval Training Equipment Center (NAVTRAEQUIPCEN), Orlando, is seen as a significant advance in capability for updating software-intense trainers. This paper describes a software support environment that facilitates the modifications, testing, and baseline configuration management of software used in sophisticated trainers. The software support environment consolidates a variety of techniques into an effective capability for managing the implementation of modifications. Baseline configuration management is founded on the implementation of operational procedures that make it easy to adhere to configuration guidelines but difficult to get changes into the system by other means. Automated identification of global symbol generation and usage greatly reduces risk of unforeseen change impact on other routines. A trainer software structure is described that permits modification of source code without patches and without the normal complete link-edit procedure. A communication link facilitates rapid turnaround in the modification and test cycle. Potential support of trainers with different computers is identified. Further, the SSF reality makes possible the overall integrated environment of "man" and "machine" for management, control and visibility for software support.

## INTRODUCTION

The maintenance of software or "software support" is an ever increasing necessity as the complexity and the number of software-intense trainers grow. Consistancy between these emergent trainers and their corresponding parent operational systems require support procedures that provide both, rapid and accurate update methodology. Digital computer software support for training devices, therefore, is to be accomplished through a field network of engineers, programmers and technicians utilizing telephone data transmissions and engineering facilities. The Software Support Facility, designed initially for the A-6E Weapon System Trainer (WST) (See Figure 1), forms the nucleus of the software support concept.

The Software Support Facility (SSF is located at the Naval Training Equipment Center (NTEC) Annex at Herndon, Orlando, Florida. Funded by NAVAIR, the SSF marks a first at NTEC for providing an in-house capability for its software support of a major trainer. Its dedication signifies recognition that support of trainer software necessitates the establishment of a "computer environment" that can facilitate the modification, testing and the management of software packages resident on current trainers. This environment can be extended to support, by judicious facility growth in accordance with the added workload, many of the software-embedded training devices planned for, or existing, in the NAVY inventory.

The new Software Support Facility or "SSF" is an outgrowth of the Software Development Facility created by Grumman Aerospace Corporation. (1) This recent innovation is designed to centralize the software support function and to act as the major element in servicing and supporting training devices located in multiple remote sites. Noteworthy is the establishment of the communication links between NTEC and the trainer sites at NAS Oceana, Virginia, and NAS Whidbey Island, Wash. via Remote Job Entry (RJE) and time-share terminals. These RJE terminals make possible the centralization of an SSF and allow the utilization of the combined resources at remote sites as well as at the SSF to accomplish the necessary rapid software changes. This centralization philosophy promotes a more cost-effective solution to the software support function and forms the catalyst for the support approach to all digital computer driven training devices. This is made possible by the availability of Software Management Tools to facilitate systematic software modifications coupled with a methodical procedure to perform the software accountability or "configuration management" function over trainer software. These tools, working in conjunction with a file oriented data base, provide flexible report generation, software modification tracking and software configuration control. The "software tools," for example, allow the automation of the process for modifying source code (without the need for patches to executable code) and the compilation and transmission of only the affected segment of the software; this segment is then installed at the site without the necessity of the typical complete link-edit procedure.

From the nucleus of this A-6E/WST SSF, extended software support is planned for existing and future digitally based trainer systems. This extension implies that continuity of SSF operating procedures

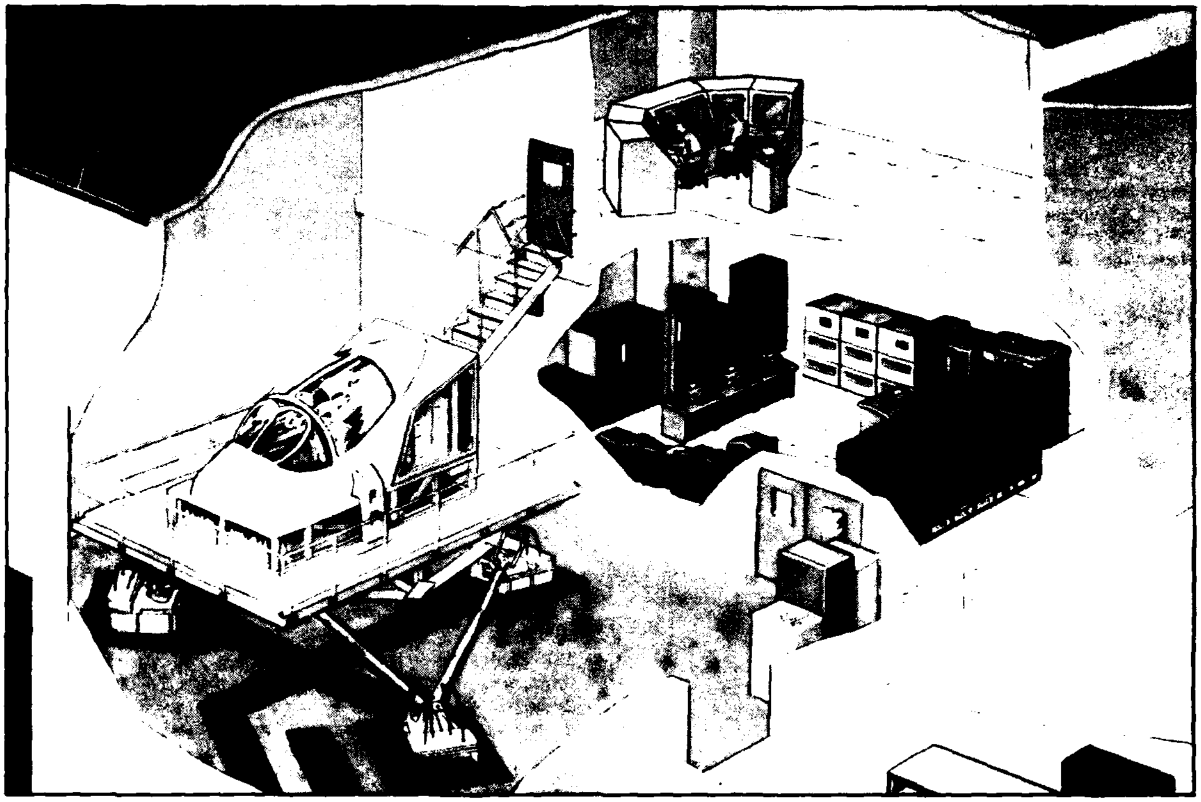

Figure 1. A-6E/WST

persist as additional digital host computers are annexed to the SSF. As long as the software support can be implemented with as few differences (computer languages, etc.) as possible, the personnel requirements for this centralized software support can be minimized.

## SOFTWARE SUPPORT OBJECTIVES

The evolution of centralized software support has been motivated strongly by the realization that software contributes 70-80% of the life cycle cost of current computer systems.(2) Further, it is recognized that computer embedded systems (i.e., trainers, etc.) that remain in the inventory for long periods (5-10 yrs) also follow this same trend in resource allocation. Concurrently, the flexibility inherent in software-intense devices necessitate an "automated environment" to let the computer handle procedural functions automatically (i.e. compiliations, assemblies, memory management, etc.), while programmer modification involvement is minimized to source code change of the particular trainer program segment and/or module.

Under these considerations, the objective of the Software Support Facility is to produce a highly automated and integrated environment, in which the centralized software support function can provide service to a variety of devices. Centralization of this function implies that, in most cases, the training device will not reside at the SSF. The hardware configuration and its attendant data communication network at the SSF, therefore, provide, (1) rapid and accurate data transfer capability for modified trainer program segments through Remote Job Entry (RJE) terminals, and (2) trainer site time-share terminal access to "baseline" source code that is maintained at the SSF. These stipulations fuel the fire for a provision that rigorous "configuration management" or accounting software baseline be centrally controlled at the SSF. At the same time provisions for a single common source code "baseline" for both SSF and trainer site personnel is available for trainer software modifications - the best of both worlds...

In developing such a facility, goals have been selected to reduce the cost of development and support through centralization. This provides the opportunity to mechanize each trainer software "baseline" under a controlled configuration management procedure and to selectively control and enhance the value of the companion documentation. Subsidiary goals for life-cycle visibility, traceability and manageability are fallouts of the centralized configuration management implementation. Finally, the SSF computer configuration coupled with the trainer software "baseline", provides a known departure point, or platform for technological enhancements or growth whether it is accomplished in-house or contractually.

The SSF has been designed initially for A-6E/WST software support and by design follows the above guidelines. The practices and procedures are common to most training devices. Additional devices are anticipated to, one-by-one, join the A-6E/WST in the SSF environment, thereby reducing substantially the cost of life-cycle support for trainers. This is based on the continuing requirement caused by update and change of operational equipment, enhancements to training or operational value, additional capabilities, system improvements for stability, error recovery or upgrading and finally, correction of deficiencies.

The balance between responsive trainer software support and cost-effective operation remains as the central issue in the SSF implementation. The SSF configuration and its environment are described next.

## SUPPORT ENVIRONMENT

The SSF environment is a combination of digital computer, communication devices, and a set of Software Management Utilities or "Tools" to automate many of the pedestrian procedures necessary to edit and construct a trainer program. The operating procedures mold this assortment of entities into a cohesive and cost-effective support system.

### Hardware Configuration

The facility currently consists of a Perkin-Elmer 8/32 digital computer, 4 disc drives, 2 tape units and associated hardware to provide direct communications with Oceana and Whidbey Island. A Versatec Printer/Plotter is used for making hard copy of the graphics data normally directed to the Instructor Console. A complement of approximately 10 Navy personnel, with the help of six (6) employees of Grumman Aerospace Corporation man the facility (See Figure 2). The computer hardware configuration is selectively tuned to the software support mission. Its core memory of one million data bytes provide sufficient space to accommodate source program storage, workload capacity, software configuration control, tracking and utility programs for the SSF and trainer site personnel to efficiently carry out their mission.

### Communication Network

The communications network currently implemented uses dial-up telephone lines to provide high and low baud rate capability for RJE and CRT terminals, respectively to Oceania NAS, Va. and Whidbey Island NAS, Washington. Figure 3 summarizes the network details, while Figure 4 shows the communications network currently in place.

### Operational Procedures

The hardware configuration provides an optimum mix for the support of centralized "software configuration management" and rapid access of baseline source programs via either SSF or field timeshare terminals. To balance the workload and limit communication transmission durations, an operational framework between the SSF and field sites is necessary.

An account structure has been installed on the SSF computer system to implement this operational environment. A "system" account heads the hierarchical account structure; it contains such programs as Command Substitution System (CSS) procedures, FORTRAN compiler, assembler, RJE communicator, data base file system (TOTAL) and other system software utilities to properly manage the varied workloads resident on the computer. Directly under the "system" account are "group" accounts which contain, (1) various categories of trainer

Figure 2. Software Support Facility (SSF)

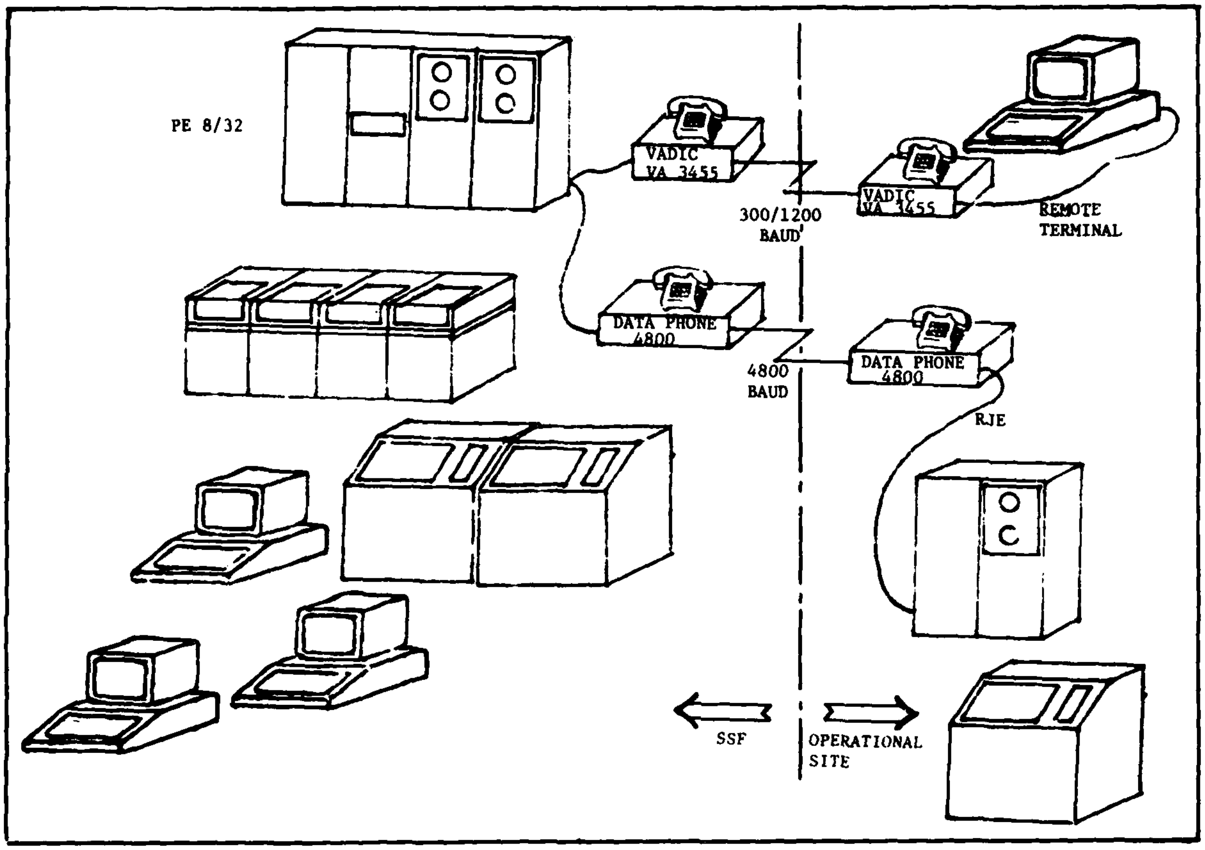


Figure 3. SSF to Site Communication Capability

"baseline" source programs, (2) software tool programs, and (3) software system component programs (i.e. I/O, Graphics pages, etc.). At the third level, private accounts are established beneath the system and group accounts, in which modifications are carried out by SSF and field personnel. The system and group accounts are protected from change by giving access through password to a selected few in the SSF; in particular, to the configruation management personnel. Private accounts can read from accounts above in hierarchy, but cannot change or replace programs in these accounts; this is reserved for the configuration management function.

In this way, modifications can be made in parallel (private accounts have access to source code baseline) and submitted to configuration management for approval. Configuration management, in turn, then processes these modifications according to a methodical procedure, including Software Review Board approval, compilation of the new module, generation of a new task segment or "overlay" (configuration management tools are available that automate much of this procedure) and the transmission of the "overlay" to the appropriate trainer sites over the communication network. Following this sequence, the site personnel install this overlay on the designated trainer and carry out the appropriate test programs to verify the software modification. The final step is then for the configuration management personnel to update the software baseline at the SSF on the successful completion of the trainer test. If deficiencies are found during the test sequence, they are recorded on the Test Discrepancy Report and modification continues until all deficiencies are corrected.

*Software Management Tools*

Salient features of the software design for the A-6E/WST were selected to create both a stable development and a stable support environment. This in turn, stabilized the procedures and yielded a generalized set of Software Tools that could be used to automate many of the configuration management and modification functions. In extending these tools to future trainer support, trainer software design features that are desirable to take maximum advantage of this generalized support environment are given as follows:

(1) Modularized software structure.
(2) Some categorization scheme that will permit assignment of unique identification numbers in logical manner.
(3) Descriptive information on each module.
(4) Established Mnemonic convention format for symbols, modules, etc.
(5) Higher Order Language (HOL)
(6) Partitioning of large-scale programs to implement source modifications that will not require excessive transmission time to site.

The Grumman developed Test and Configuration

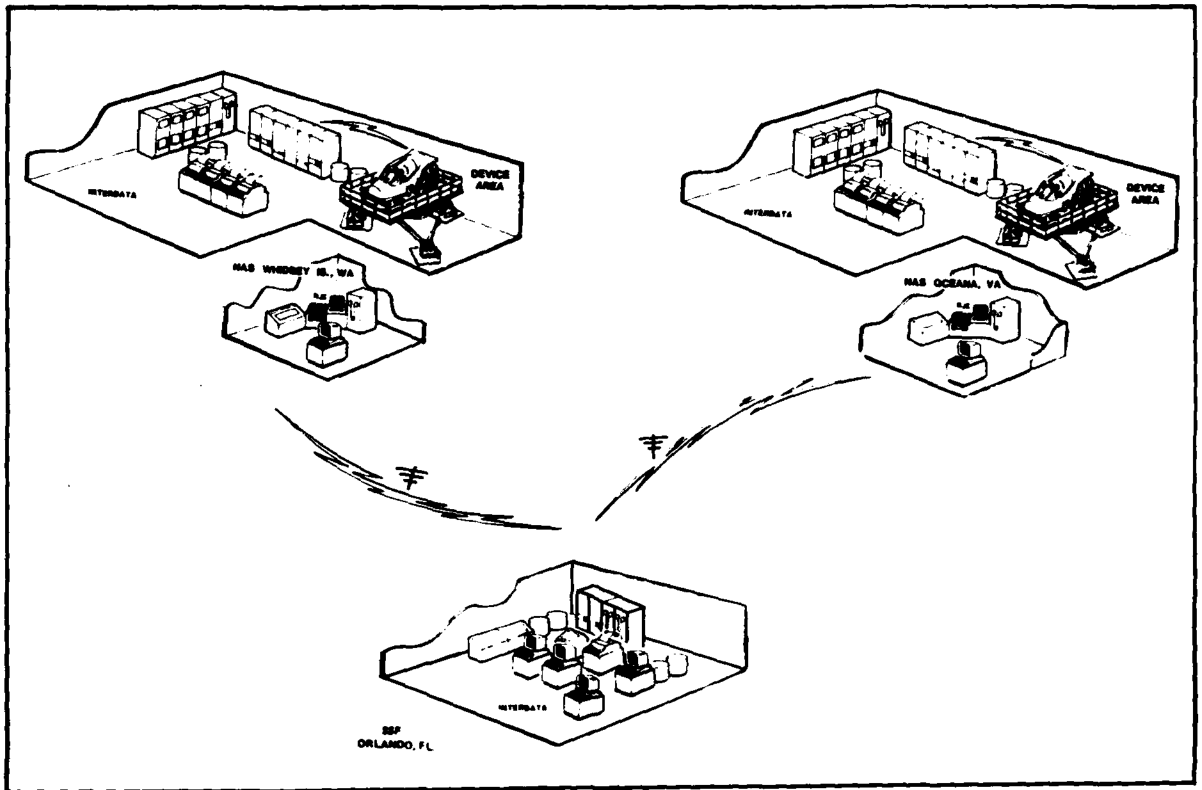


Figure 4. SSF Communication Network

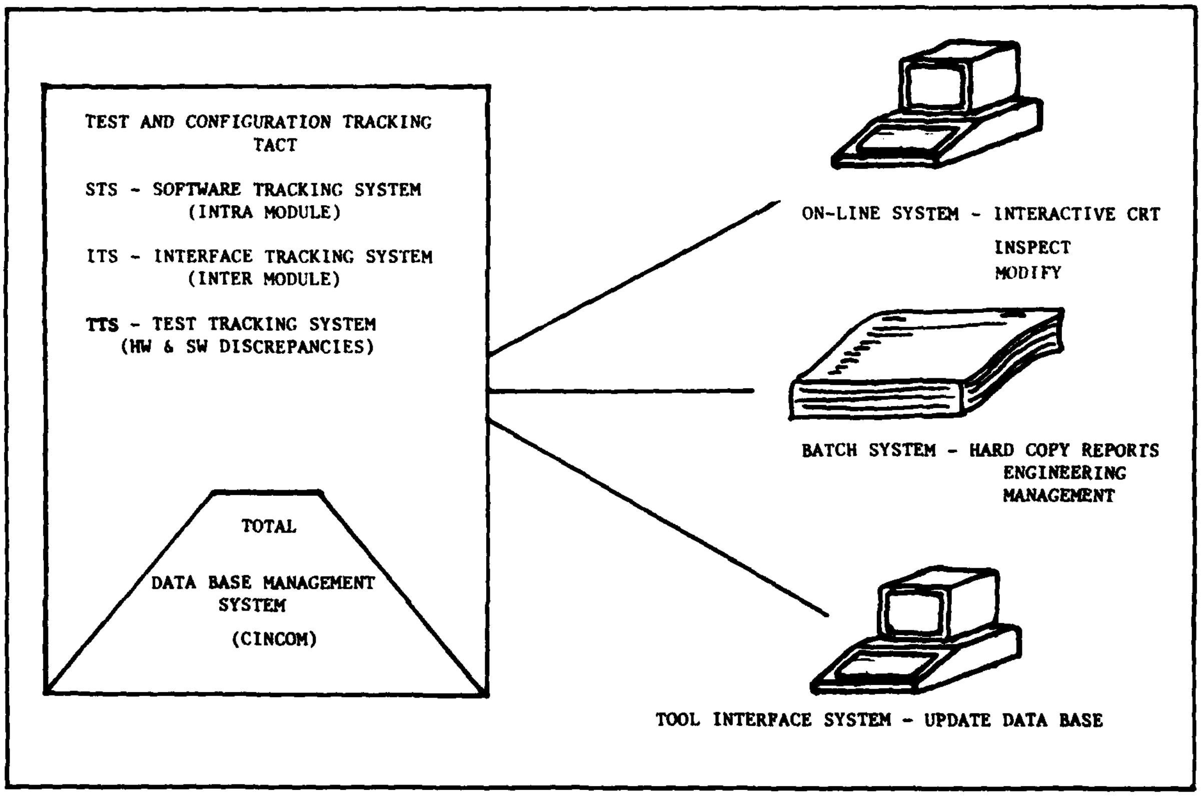


Figure 5. TACT System Configuration

Tracking System (TACT) is a file oriented data base system that combines a technical reporting system with a management information system. It is supplemented by analysis and test support tools that further enhance the flexibility for data base control, and for the analysis of "as-built" code.

The TACT system (described in more detail in reference 1) is operated in two modes, (1) on-line system, with interactive control for quick-look inquires and data base update and, (2) batch report, hard copy processing. Three major functional subsystems makeup the TACT system; they are:

(1) Software Tracking System (STS)
(2) Interface Tracking System (ITS)
(3) Test Tracking System (TTS)

The TACT system utilizes the TOTAL data base management system marketed by CINCOM, Inc. The TACT system configuration is shown in Figure 5.

The software tracked by the TACT system is organized into a hierarchical structure so that each subsystem/module is identified with a unique Hierarchical Identification (HID) code. The Software Tracking System (STS) is used to collect and track, through a module data base, various parameters of each module. Data such as module name, mode usage, execution order, execution time, core size actuals, input and output mnemonic names, version level, source language and cognizant engineer, are a few of many variables that are used to describe the anatomy of each module. In the support role, it is crucial to maintain this data base through the various modification projects for each device. The STS system serves the role of maintaining this fundemental data base as a part of the software configuration baseline.

The Interface Tracking System (ITS) automates the handling of module interconnect variables and the signal variables between the software and the trainer hardware. A Data Element Dictionary (DED) and Signal Description List (SDL) are examined by subordinating programs that supply the ITS with current interface data. These programs basically assist in the automatic generation of all the interface parameters of the system. The ITS plays a significant role in the software modification procedure by automatically identifying, for a given change of variable, the modules and parameters affected by that change. The extent or the resources needed, for a software change can be quickly assessed by the use of this portion of TACT. An ancillary program, Automatic Interface Mneumonic Extractor System (AIMS), is used to systematically dissect a software module to classify, extract and identify the attributes (global vs local or input vs output, etc.) of module variables across a spectrum of FORTRAN, assembly code or a mixture thereof. The AIMS builds the data base for the ITS program. Through this medium various reports can be gathered to identify missing inputs, unused outputs or other pertinent data necessary to insure the integrity of a modified trainer program.

The Test Tracking System (TTS) is an information management system which maintains a data base that references test procedures and the resultant Trainer Discrepancy Reports (TDR). The elements maintained are the current, relevant test procedures by module or by mode, the responsible engineer, subsystem name, description of discrepancy or change and its disposition. Reports are automatically generated (in batch mode) for the day-to-day, week-to-week tracking of these TDR's. They are to be used by the various levels of management for resource allocation, for failure analysis, for visibility of trouble spots, etc. A "quick look", as well as, update of TDR data base are available through an "on-line" TTS terminal.

Access to the TACT system via CRT terminal from the trainer sites either on-line or batch, is provided through the VADIC modem in a time-shared mode. It, in fact, gives the site personnel access to the appropriate source programs, software tools, compilers, etc., that reside on the SSF. These software utilities are summarized in Figure 6. [1]

Various software tools are also available at the SSF to maintain the baseline configuration of the trainer software. The procedure for the maintenance of the software baseline is a methodical discipline put in a centralized location (for more than one device location), to track, control and record the history of change for a given trainer. Figure 7 [1] illustrates the steps necessary to not only maintain the software baseline, but also to coordinate the configuration updates to the documentation. These software tools (1) provide complete tracking and identification of all authorized changes, (2) include header/trailer programs to emplace configuration identity and quality assurance information on each source file, (3) include configuration accounting programs for listing software components and revision levels and for automatically extracting configuration data from header/trailer blocks, and (4) generate all load modules from computerized configuration control records.

The automated configuration management tools and the procedures laid out in Figure 7 are leading toward the generation of an overlay which is ultimately transmitted to the trainer site. The overlay is a program segment which has undergone a modification under a change order, recompiled and structured into the form of an executable load module for installation on the appropriate trainer. The overlay is directed to a specific window in memory that normally contains the approved revision level of code. The overlay is structured to intercommunicate with other overlays via Fortran Labeled Common which avoids the need to link-edit the entire program. This automated sequence includes the verification of compliance to the baseline configuration prior to any processing of a change component. It concludes with the acceptance testing after installation and the revision and release of the new software configuration baseline.

## EXTENDED TRAINER SUPPORT PLAN

The rationale for centralizing the resources for the trainer device software support becomes stronger as the number of training devices at different locations increase. This is substantiated by a recent study [3] prepared by Computer Sciences Corporation for NAVTRAEQUIPCEN Code N-412, Orlando, Florida.

### Short-Term Extension of SSF Capability

Under this plan, [4] SSF-configured host

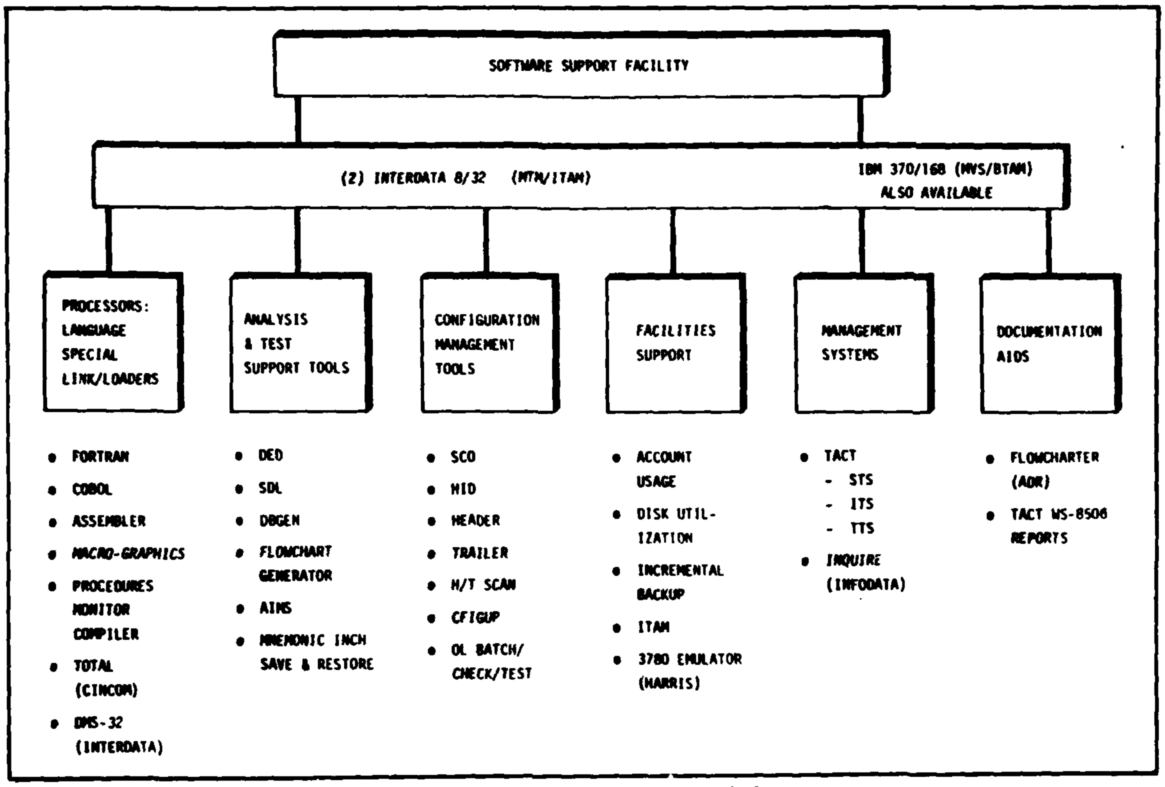


Figure 6. SSF Software Support Capability

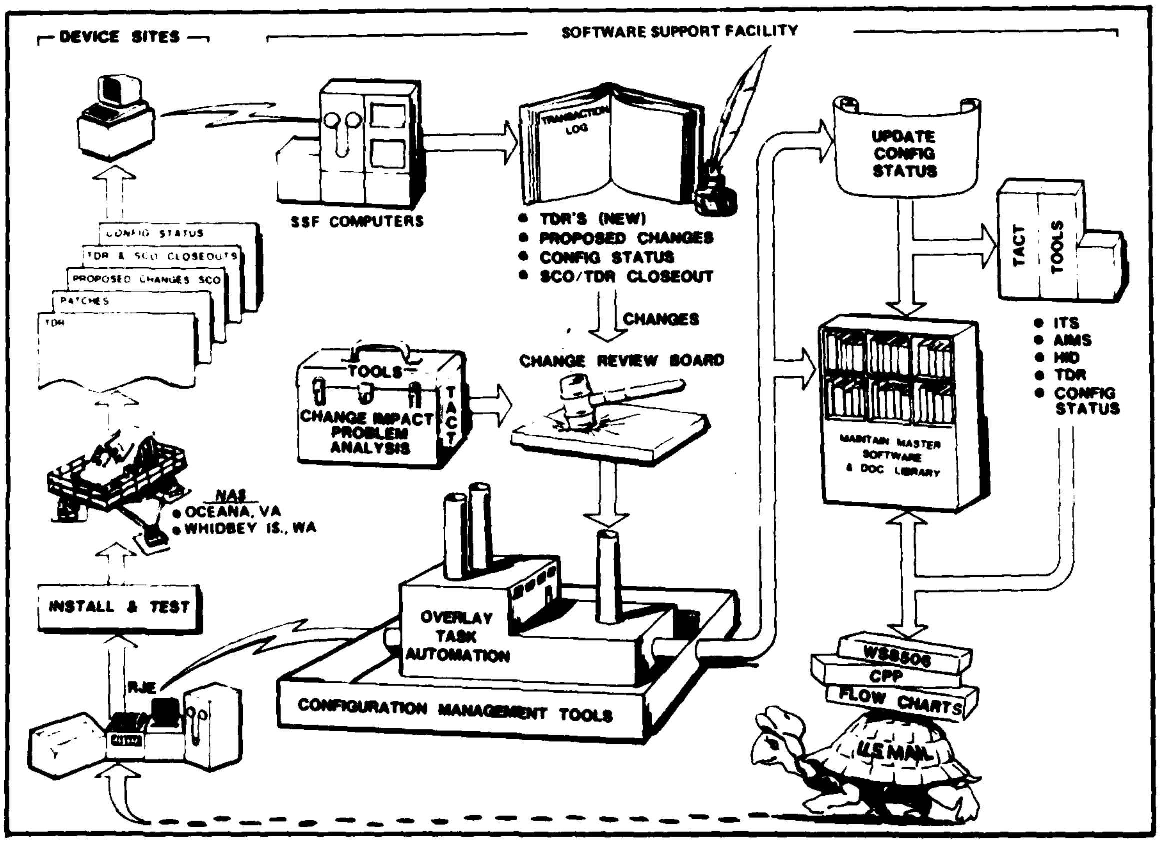


Figure 7. Configuration Management Procedure

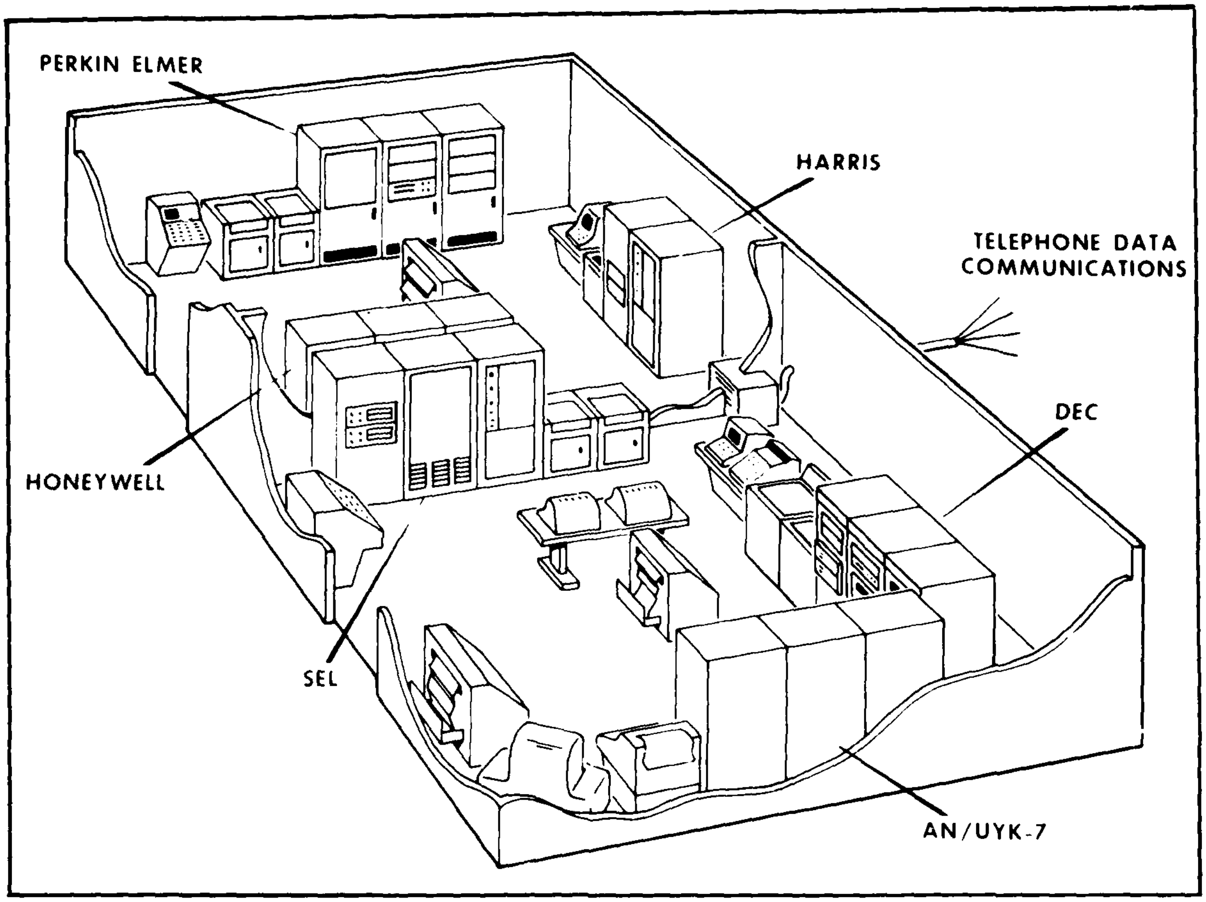


Figure 8. Proposed Orlando Software Support Expansion

computers (supporting an additional and appropriate segment of NAVY training devices) would sequentially be added to the existing SSF. This expanded facility is shown in Figure 8. The management tools already described are to be modified and be compatible with these additional host computers; the communications network would also be expanded to three main dedicated telephone circuits (shown in Figure 9) to service most of the Naval training facilities within the CONUS.

The procedures and practices now implemented at the SSF are seen to be common to the expanded SSF. This commonality, in turn, will provide a manpower cost-effective base on which to operate the centralized facility.

Long-Term SSF Implementation Goal

Greatly improved performance with minimum duplication of both effort and hardware may eventually be provided through the restructuring of the Software Support Facility to include a mainframe computer. In this configuration many of the software tools would be combined and implemented on the mainframe computer , thereby eliminating the need both for supporting multiple implementation of all the tools on separate minicomputers at the SSF and for extending implementation of those tools when additional minicomputers are brought into the SSF. The mainframe computer would be interconnected with minicomputers within the SSF to provide a capability for using compilers, assemblers, link-editors and utility packages from the OEM of the target computers. In some cases emulation of target computers would be used so that certain computers would not have to be maintained within the SSF environment. Communication links would connect with the mainframe computer rather than with each separate minicomputer. The mainframe would direct data to a minicomputer for compilation, assemblies, or link-edit as appropriate and receive the results for storage. Minimal auxiliary storage would be dedicated to each minicomputer for working storage.

The implementation thus described would greatly facilitate operations both local and from the field. Locally there would be reduced duplication of equipment and procedures among the numerous computer systems involved. The consolidation of trainer configuration baseline management into a mainframe computer not only reduces the need to learn multiple systems but also tends to provide opportunities for global analysis of multiple baselines across numerous target computers. The modification efforts, both local and field-based, can be implemented using a single text editor and common operating procedures regardless of the identity of the target computer involved. The primary aspect of modification that cannot practically be made transparent to the user are the

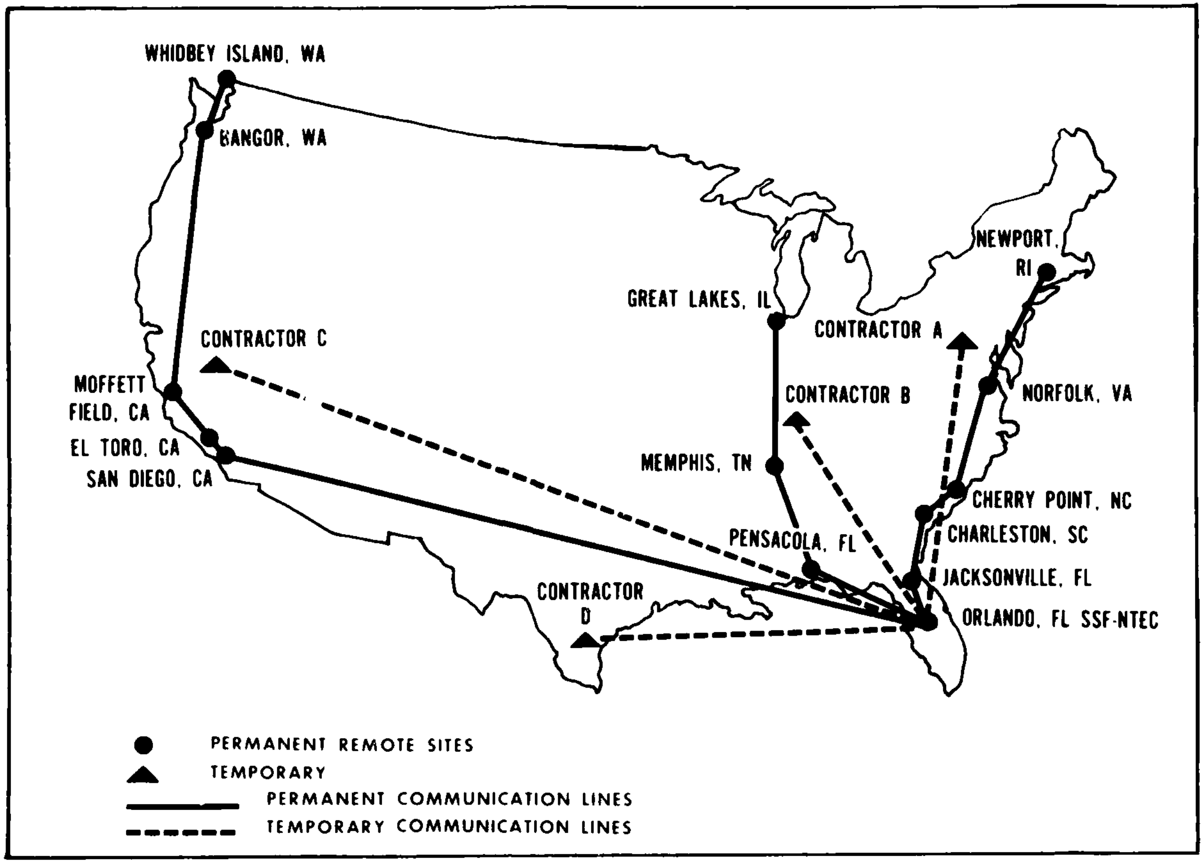


Figure 9. Training Devices Software Support Network

language differences and the software testing efforts associated with the different target computers.

The benefits of establishing a centralized Software Support Facility for use by local and field modification efforts rise to their maximum potential with the implementation of software tools on a centralized mainframe computer.

## SUMMARY

The centralized SSF environment provides a cost-effective method for the implementation of software support to training devices widely distributed in location. It enhances the use of key software skills, encourages software commonality, makes use of common software maintenance tools and standards and reduces redundant support hardware.

This centralized facility provides the software baseline control or configuration management function that for so long has been missing. It accomplishes this while allowing the primary device to function on its intended mission. The flexible communication network allows maximum accessibility to authorized NAVTRAEQUIPCEN field personnel so that the most knowledgeable people on trainer operation can be used to diagnose problem areas. All the power of the SSF environment is virtually at the disposal of the field personnel.

Incremental change and growth are a way of life for large software systems. Design evaluation, aircraft updates and changes, and the addition of features to enhance training value require a well-coordinated and automated software support environment like that available at the SSF. The SSF also serves to reduce the cost of these functions and increase the life-cycle traceability and manageability of the software support; the direct accessibility to source programs, processors, tools and documentation; and direct data communication to the device sites.

The SSF serves as a "baseline" for extending central software support to other trainers with their attendant target computers. The Software Management Tools and Procedures, for example, are essentially applicable with some adjustments to those applications. The orchestration of the procedures necessary to efficiently deliver this service to the Fleet is, and will remain, the primary mission of the Software Support Facility.

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## ABOUT THE AUTHORS

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# PENALTY/INCENTIVE CONTRACTOR SUPPORT FOR TRAINING DEVICES

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## ABSTRACT

As budget limitations continue and shortages of experienced military personnel persist, more and more attention is being given to alternative support concepts, particularly when they offer potential cost savings or cost avoidance while meeting equipment availability requirements. This paper examines current alternatives to conventional training device support concepts with emphasis on Fixed-Price, Penalty/Incentive Contractor Support (FPPICS).

## BACKGROUND

The Naval Training Equipment Center has been providing training equipment to the Navy for over three decades. In that time, equipments have undergone a dramatic change in scope, complexity and cost. The current Navy training equipment (COG "20") inventory includes devices from simple inexpensive cutaways to state-of-the-art air trainers with six degrees of freedom motion platforms, computer imagery and a vast array of digital/hybrid circuitry.

The current value of the inventory of training equipments, and the near term projected acquisitions will push the value of this equipment and that of other services into the billions of dollars.

As expensive as the acquisition cost of this hardware may be, the cost of ownership can easily surpass the acquisition cost. When one considers owning this equipment for 15 to 20 years, the cost of ownership becomes staggering.

The Naval Training Equipment Center has supported these equipments in numerous ways over the past three decades, but rather than present an anthology of these support systems, it would be more appropriate to describe the current support mechanism as it exists today for the majority of training devices.

### Conventional Support Methods

When a major training device is procured, the Naval Training Equipment Center also procures interim support from the prime contractor to allow the Government support system time to become operational. Interim support is typically for a twelve-month period and includes an on-site contractor representative, interim spare parts and preliminary documentation. During this interim support period, the contractor is fully responsible for ensuring the training device is operational.

The Navy support system is typically composed of Navy Training Device Technicians (TRADEVSMEN-TD's) to support the training unique equipment, and fleet experienced personnel to support operational Government Furnished Equipment (GFE). These technicians may include Electronics Technicians (ET's), Sonar Technicians (ST's), or Data System Technicians (DS's) to name only a few.

The fleet experienced personnel normally need little or no training since they have experience on the operational systems. However, training unique equipment has no fleet operational counterpart and TD's normally undergo extensive training courses in operation and maintenance of training unique equipment. Since the percentage of training unique ("simulated") equipment continues to increase, it is not uncommon for these courses to extend for as long as six months to a year in length. These technicians will normally perform the preventive and corrective maintenance at the organizational and intermediate level, with depot level repair being reserved for a major support facility or a contractor.

To aid the Navy technicians, a civilian on-site Government technical representative called the Field Engineering Representative (FER) is provided. The FER is the on-site technical expert as well as the liaison between the civilian support agency and the military community.

The Naval Training Equipment Center procures a myriad of technical information in the way of drawings, reports, handbooks, manuals and documentation to assist these individuals in the maintenance required functions support to the device. The costs of this technical documentation has been rising in spite of efforts to reduce or contain them and frequently runs into the millions of dollars.

To back up the on-site Government support organization, there are three field office extensions of the Naval Training Equipment Center. The field organizations are located in San Diego, California; Norfolk, Virginia; and Pensacola, Florida. These support centers provide engineering, software, and maintenance/logistic support to the device sites.

To complete the support program of the Government, there must be a mechanism to supply and replenish parts. As mentioned earlier, the Government procures interim spare parts to be delivered with the device. At a later date, the Naval Training Equipment Center will furnish the using command with funds to procure Initial Outfitting parts, and the Aviation Supply Office, Philadelphia, Pennsylvania, will procure parts and stock them at a supply facility remote from the device sites.

This then, is the basic structure of the conventional Government support system for training devices. While experience has shown that this support system does work and generally meets training needs, there are many inherent problems associated with the basic nature of this system that prohibit it from being cost effective over the life cycle of the device. These problems are summarized below:

- Training device technicians (TD's) rotate from device to device every 2 to 3 years.
- The large majority of TD's are inexperienced technicians.
- The Navy is having a difficult time retaining experienced maintenance technicians in today's high technology environment.
- The Government receives constant pressure to reduce the federal billet structure both military and civilian.
- Electronics state-of-the-art is constantly changing.
- TD's as a rule do not stay in the same training device community upon transfer; i.e., air, surface, subsurface devices, necessitating even longer retraining courses.
- The Aviation Supply Office is set up to support multiple unit aircraft, rather than the small population of unique training devices.
- The field support organizations are having a difficult time recruiting and retaining qualified software personnel.

This is not meant to be a comprehensive list of problems but rather an overview of the more serious problems. With this support scenario in mind, it is time to explore other more cost effective support systems for training devices.

## Experience Summary

Contractor support is not new. The Air Force and the Navy have used it to support training aircraft and training equipment on a continuing basis and as mentioned above, many contracts contain "interim contractor support" provisions for support of new equipment during the initial deployment phase while the government capability for support is being acquired/developed.

The Naval Training Equipment Center as a matter of course routinely contracts for "interim contractor support" to allow the Government sufficient time to initiate Government support. The interim contractor support is generally one year in length, buy may be significantly shorter if the nature of a device warrants it.

The Government's experience with interim contractor support has shown a high device availability with excellent parts support from the contractor. In general, device availability has declined after the end of the interim contractor support period when the contractor has left the site. In addition, most contractors have experience in support of their own equipment. At Gould Inc., Simulation Systems Division, support has been provided across the full spectrum from conventional support to fixed-price, penalty/incentive contractor support - the subject of this paper. The fixed-price, penalty/incentive concept has been used on the T-34C CPT program very successfully. It is also planned and is being implemented for the T-34C FIT and T-44 OFT programs. In addition, the concept has been proposed, in many cases at Government request, for several recent programs including the F-18 Trainer Family, the Reactive Electronic Equipment Simulator, and the MK-23/MK-86 Gun Fire Control System Simulators.

## ALTERNATIVES

The alternatives examined in this paper include conventional support, Contract Maintenance Services (CMS) support, commercial computer support, fixed-price support without penalty/incentive and Fixed-Price, Penalty/Incentive Contractor Support (FPPICS). Table 1 summarizes these alternatives from a management and support viewpoint and is referenced throughout the following discussion.

### Conventional Support

Conventional support, as described previously, is the most frequently used concept at this time. Because of the extent of experience with this approach, it has become very highly defined with limited flexibility. Recent efforts indicate that some flexibility may be restored to this approach by encouraging prospective bidders to suggest alternative methods of meeting specific support element requirements if support is not jeopardized and the requirements in questions can be met more cost effectively. However, this flexibility has seen very limited implementation to date.

### Contract Maintenance Services (CMS) Support

Contract Maintenance Services is very similar to conventional support. It is normally procured as a cost-plus type services contract. Essentially, service contracts involve the contractor providing support personnel in lieu of uniformed or Government civil service personnel, usually the full range of support element requirements remains in the equipment acquisition contract. Therefore, limited costs savings potential exists, primarily from a lower turnover and training rate associated with contractor personnel and from potentially lower contractor manning levels compared with military (approximately 0.75:1).

### Commercial Computer Support

Commercial computer support of digital computers by contractor maintenance services allows the Government the flexibility of establishing conventional support for much of the training unique portion of the trainer, while having the advantage of contractor support of the computer system. Many training devices are using state-of-the-art high speed commercial digital computers that have a support organization already in place from the computer manufacturer. This can provide a more cost-effective alternative to the requirement to provide Government technicians with the lengthy training necessary for maintenance of these computers, as well as the requirement t...

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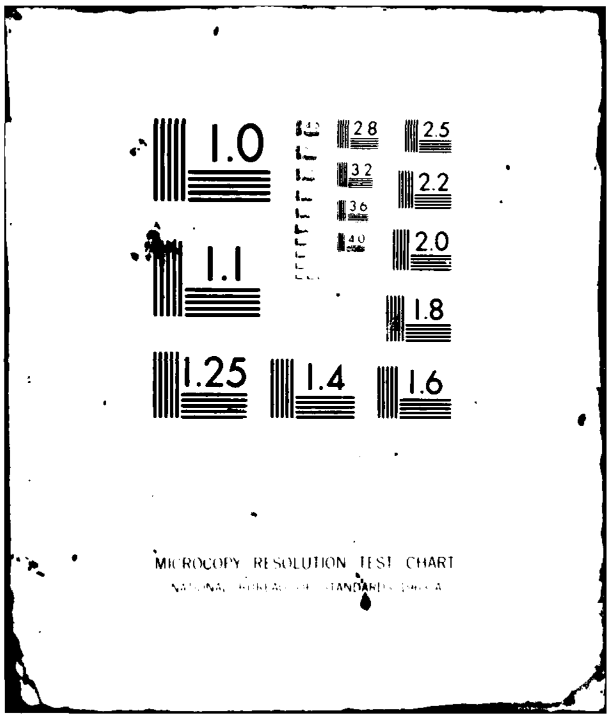
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TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW

CONVENTIONAL SUPPORT VS. CONTRACT MAINTENANCE SERVICES

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | CONTRACT MAINTENANCE SERVICES (CMS) SUPPORT | COMMENTS |
|---|---|---|---|
| | | MANAGEMENT CONSIDERATIONS | |
| Type of contract | N/A | Maximum funded level of effort. | Normally either cost plus or fixed-price labor with cost plus for material. |
| Risks: - Cost Liability | Government assumes responsibility. | No contractual limit. | As required by program. |
| - Transition | Minimal - up front acquisition. | Minimal - up front acquisition. | |
| Availability (Operational) | Government assumes responsibility. | Goal only. | R/M program provides some confidence of inherent equipment availability. |
| Cost Control | Government assumes responsibility. | Open ended-level of effort budgetary estimate. | |
| Cost Visibility | Government assumes responsibility. | Contractual reporting requirements. | |
| Incentives | Conventional contractual incentives. | Conventional contractual incentives. | |
| Configuration Control | Standard military procedures. | Standard Configuration Management. | |
| Maintenance Management and Site Feedback | Standard military procedures - (3M system). | Service procedures + contractor procedures. | Product improvements may be recommended including cost impact. |
| | | LOGISTIC SUPPORT CONSIDERATIONS | |
| Maintenance/Repair Concept | Per maintenance analysis; geared toward government support. | Styled after standard government support. | Maintenance concept normally specified by contract. |
| Logistic Support Analysis | Tailored to contract (includes deliverables). | Per ILSPR/CDRL. | LSA adjusted to reflect contractor maintenance - no cost savings potential. |
| Reliability/ Maintainability | Full program with demonstrations. | Full program including demonstrations. | |
| Technical Manuals | Full to maintenance concept. | Manuals per CDRL. | Normally no savings potential. |
| Training | Full maintenance training to the maintenance concept with 2-year turnover of maintenance personnel. | Contractor field maintenance pre-operational training. | Initial maintenance training for contractor personnel reduced. Reduced turnover. |
| Provisioning | Full to maintenance concept with deliverables. | Full exhibit "C" effort coincident with LSA. | Normally no savings potential. |

TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW (Cont.)

CONVENTIONAL SUPPORT VS. CONTRACT MAINTENANCE SERVICES (Cont.)

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | COMMERCIAL COMPUTER SUPPORT | COMMENTS |
|---|---|---|---|
| Spares | Full in accordance with maintenance concept. | Contract line item; (max funded) based on Gov't support methodology. | Normally no savings potential. |
| Test Equipment | Standard requirements in accordance with maintenance concept. | Contract line item, (max funded) based on Gov't support methodology. | Normally no savings potential. |
| Manning | Variable depending upon availability of personnel and skills. | Contract line item (max funded) based on Gov't support methodology. | Some reductions may be possible depending on size of support effort. |

CONVENTIONAL SUPPORT VS. COMMERCIAL COMPUTER SUPPORT

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | COMMERCIAL COMPUTER SUPPORT | COMMENTS |
|---|---|---|---|
| | | MANAGEMENT CONSIDERATIONS | |
| Type of contract | N/A | Vendor service. | Can be service agreement ($/mo.) or service call rate. |
| Risks: | | | |
| - Cost Liability | Government assumes responsibility. | Normally fixed rate per month or service call. | Based on number of calls. |
| - Transition | Minimal - up front acquisition. | Government assumes risk. | Vendor manuals are normally included as part of device contract. Include option for commercial training. |
| Availability (Operational) | Government assumes responsibility. | Dependent on vendor response times. | |
| Cost Control | Government assumes responsibility. | Government assumes responsibility. | |
| Cost Visibility | Government assumes responsibility. | Government assumes responsibility. | |
| Incentives | Conventional contractual incentives. | Conventional contractual incentives. | |
| Configuration Control | standard military procedures | Normally assigned to vendor. | Updates performed by vendor rep. as required. |
| Maintenance Management and Site Feedback | Standard military procedures - (3M System) | Vendor service call procedures. | Government may transcribe data to Maintenance Data Collection System. |
| | | LOGISTIC SUPPORT CONSIDERATIONS | |
| Maintenance/Repair Concept | Per maintenance analysis; geared toward Government support. | Tailored to vendor service guidelines. | Heavy use of computer vendor factory repair. |
| Logistic Support Analysis | Tailored to contract (includes deliverables). | Not applicable to computer. | Proportional savings for computer related LSA (as applicable). |
| Reliability/ Maintainability | Full program with demonstrations. | Not applied to commercial subsystems. | Proportional cost savings. |

TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW (Cont.)

CONVENTIONAL SUPPORT VS. COMMERCIAL COMPUTER SUPPORT (Cont.)

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | COMMERCIAL COMPUTER SUPPORT | COMMENTS |
|---|---|---|---|
| Technical Manuals | Full to maintenance concept. | Vendor manuals normally supplied with device. | Minimal cost savings opportunity. |
| Training | Full maintenance training to the maintenance concept with 2-year turnover of maintenance personnel. | Minimal maintenance training on computer (operation only). | Significant savings since computer maintenance is major element of training. |
| Provisioning | Full to maintenance concept with deliverables. | None - use of vendor service manuals. | Proportional savings for computer related information. |
| Spares | Full in accordance with maintenance concept. | Use of vendor procedures or spare whole computer system. | Savings dependent on spares methodology used. |
| Test Equipment | Standard requirements in accordance with maintenance concept. | Common support equipment only. | Avoidance of special test equipment for computer/peripherals. |
| Manning | Variable depending upon availability of personnel and skills. | Reduced to extent computer related. | Proportional savings for computer related manning. |

CONVENTIONAL SUPPORT VS. FIXED-PRICE SUPPORT WITHOUT PENALTY/INCENTIVE

| ELEMENT FACTOR | CONVENTIONAL SUPPORT | FIXED-PRICE SUPPORT WITHOUT PENALTY/INCENTIVE | COMMENTS |
|---|---|---|---|
| | | MANAGEMENT CONSIDERATIONS | |
| Type of contract | N/A | Fixed-price (labor and material). | Contract includes clauses for not to exceed price quotes on 2 option years. Contract value renegotiated annually. |
| Risks: | | | |
| - Cost Liability | Government assumes responsibility. | Limited by fixed-price amount. | Contract provides Life Cycle Cost savings. |
| - Transition | Minimal - up front acquisition. | Requires transition package option. | Package option includes conversion of sufficient minimal data for development of full organic documentation required. |
| Availability (Operational) | Government assumes responsibility. | Goal only. | |
| Cost Control | Government assumes responsibility. | Fixed-price contract. | Costs can change with annual renegotiation of support contract (inflation effects primarily). |
| Cost Visibility | Government assumes responsibility. | ECP's incluce fixed-price or NTE support impact. | ECP costs are presented as fixed-price changes to the support contract. |
| Incentives | Conventional contractual incentives. | Same as conventional and provision for R/M product improvements. | Implied incentives-associated with fixed-price contract. |

TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW (Cont.)

CONVENTIONAL SUPPORT VS. FIXED-PRICE SUPPORT WITHOUT PENALTY/INCENTIVE (Cont.)

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | FIXED-PRICE SUPPORT WITHOUT PENALTY/INCENTIVE | COMMENTS |
|---|---|---|---|
| Configuration Control | Standard military procedures. | Same as conventional + provision for R/M product improvements and compatibility changes. | Contractor has additional incentive to incorporate R/M data feedback and institute product improvements. |
| Maintenance Management and Site Feedback | Standard military procedures - (3M System). | Same as CMS + used to initiate product improvements. | Product improvements are implemented because of incentive to improve product integrity and availability. All changes would indicate support impact (if any). |
| | | LOGISTIC SUPPORT CONSIDERATIONS | |
| Maintenance/Repair Concept | Per maintenance analysis; geared toward Government support. | Tailored to contractor/commercial support methods. | |
| Logistic Support Analysis | Tailored to contract (includes deliverables). | Internal analysis only used to definitize support approaches/costs keyed to Availability goal. | Significant savings in contractual value of Logistics Support Analysis Program potential savings up to 95%. |
| Reliability/Maintainability | Full program with demonstrations. | Sames as CMS. | |
| Technical Manuals | Full to maintenance concept. | Preliminaries only (system level) + commercial documentation and drawing package. | Potential savings of 50% of Technical Manuals program. |
| Training | Full to maintenance concept. | May require fewer personnel to be trained. | Formal course/training data not deliverable. |
| Provisioning | Full to maintenance concept with deliverables. | Limited/tailored to contractor style parts list. | Potential savings of 75% of Provisioning documentation program. |
| Spares | Full in accordance with maintenance concept. | Selected subsystems may be purchased as complete units ("test bed" approach). | Spares may be procured as full subsystems providing for lot size economies. |
| Test Equipment | Standard requirements in accordance with maintenance concept. | Test bed approach. | Test-bed would allow for off-line troubleshooting utilizing the test bed (less test equipment to procure and maintain). |
| Manning | Variable depending upon availability of personnel. | May require fewer support personnel. | Life cycle savings. |

CONVENTIONAL SUPPORT VS. FIXED-PRICE, PENALTY/INCENTIVE CONTRACTOR SUPPORT

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | FIXED-PRICE, PENALTY/INCENTIVE CONTRACTOR SUPPORT (FPPICS) | COMMENTS |
|---|---|---|---|
| | | MANAGEMENT CONSIDERATIONS | |
| Type of contract | N/A | Fixed-price with penalty/incentive on trainer availability. | FPPICS contract includes clauses for not to exceed price quotes on 2 option years. Contract value renegotiated annually. |
| Risks: | | | |
| - Cost Liability | Government assumes responsibility. | Limited fixed-price amount. | Contract provides Life Cycle Cost Savings. |

TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW (Cont.)

CONVENTIONAL SUPPORT VS. FIXED-PRICE, PENALTY/INCENTIVE CONTRACTOR SUPPORT (Cont.)

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | FIXED-PRICE, PENALTY/ INCENTIVE CONTRACTOR SUPPORT (FPPICS) | COMMENTS |
|---|---|---|---|
| - Transition | Minimal - up front acquisition. | Requires transition package option. | Package option includes conversion of sufficient minimal data for development of full organic documentation required. |
| Availability (Operational) | Government assumes resonsibility. | Guaranteed contractual availability. | |
| Cost Control | Government assumes responsibility. | Fixed-price contract. | Costs can change with annual renegotiation of support contract (inflation effects primarily). |
| Cost Visibility | Government assumes responsibility. | ECP's include fixed-price or NTE support impact. | Costs are presented as fixed-price changes to the support contract. |
| Incentives | Conventional contractual incentives. | Same as conventional + provision for R/M product improvements. | Incentives result in increased device integrity and greater utilization and achivement of training mission. |
| Configuration Control | Standard military procedures | Same as conventional + provision for R/M product improvements and compatibility changes. | Contractor has additional incentive to incorporate R/M data feedback and institute product improvements. |
| Maintenance Management and Site Feedback | Standard military procedures - (3M System). | Same as CMS + used to initiate product improvements. | Product improvements are implemented because of incentive to improve product integrity and availability. All changes would indicate support impact. |
| | | LOGISTIC SUPPORT CONSIDERATIONS | |
| Maintenance/Repair Concept | Per maintenance analysis; geared toward Government support. | Tailored to contract/ commercial support methods. | Contractor methods geared towards cost-effective maximization of availability. |
| Logistic Support | Tailored to contract (includes deliverables). | Internal analysis only used to definitize support approaches/costs. | Significant savings in contractual value of Logistics Support Analysis Program potential savings up to 95%. |
| Reliability/ Maintainability | Full program with demonstrations. | Demo's not required because of penalty/incentive, fixed-price. | Potential savings of approximately 25% of contractual R/M program. |
| Technical Manuals | Full to maintenance concept. | Preliminaries only (system level) + commercial documentation and drawing package. | Potential savings of 50% of Technical Manuals program. |
| Training | Full maintenance training to the maintenance concept with 2-year turnover of maintenance personnel. | Same as CMS; may require fewer personnel to be trained. | Potential savings measured over system life cycle. |
| Provisioning | Full to maintenance concept with deliverables. | Limited/tailored to contractor style parts list. | Potential savings of 75% of Provisioning documentation program. |
| Spares | Full in accordance with maintenance concept. | Selected subsystems may be purchased as completed units ("test bed" approach). | Spares may be procured as full subsystems providing for lot size economies. |

TABLE 1. ALTERNATIVE SUPPORT CONCEPTS - COMPARATIVE OVERVIEW (Cont.)

CONVENTIONAL SUPPORT VS. FIXED-PRICE SUPPORT WITHOUT PENALTY/INCENTIVE (Cont.)

| ELEMENT/FACTOR | CONVENTIONAL SUPPORT | FIXED-PRICE, PENALTY/ INCENTIVE CONTRACTOR SUPPORT (FPPICS) | COMMENTS |
|---|---|---|---|
| Test Equipment | Standard requirements in accordance with maintenance concept. | Test bed approach. | Test-bed would allow for off-line troubleshooting utilizing the test bed (less test equipment to procure and maintain). |
| Manning | Variable depending upon availability of personnel and skills. | May require fewer support personnel - fixed level established by contract. | Life cycle savings through FPPICS approach. Also, availability not jeopardized by manning variations. |

stocking the supply system with parts. A cost-effective option is to access the support system established by the computer manufacturer.

This approach offers cost savings in training, documentation, parts support and on-site maintenance personnel. The approach also has some risks which must be addressed:

- On-call computer services may not provide the desired availability of the training device in the event of computer malfunctions.
- Problems which involve the interface between the commercial computer and the training device may be more difficult to solve.
- Careful configuration management and control of commercial revision activity must be exercised by Government maintenance personnel. This is necessary to insure that revisions which may be incorporated by the computer manufacturer during maintenance (on-site or factory repairs) do not introduce system (hardware or software) malfunctions.
- Logistics management personnel must maintain a close, on-going awareness of commercial repair capabilities to avoid excessive dependence on a single source of support. (Many commercial repair/support agreements carry a stipulation that the manufacturer reserves the right to discontinue support with minimum notice.)

Fixed-Price Support Without Penalty/Incentive

This method offers an implied warrantee if material costs are included in the fixed-price amount since lower equipment reliability would cause increased material expenses without reimbursement. This approach also offers potential cost savings in many areas of the acquisition contract but does not offer assurance of a required level of operational performance or availability.

Penalty/Incentive Support

The introduction of the penalty/incentive feature to contractor support is the primary focus of this paper. Since the application of the penalty/incentive clause is based on trainer operational availability, a substantial confidence level in meeting operational training needs is achieved. As a result, many of the conventional controls, reviews, analyses, conferences, reports, data, tests, and demonstrations can be reduced or removed from program requirements while at the same time, taking advantage of the basic cost savings associated with the application of contractor support. As shown in Table 1, cost savings and cost avoidance associated with this concept are available in almost every element of logistic support.

Penalty/Incentive Formula

The establishment of a penalty/incentive formula must be tailored to the specific program under consideration. The formula should be based upon mutual understanding of the technical and costs risks associated with the equipment performance and support effort. In general, if the operating/support environment is well defined as described in CONCLUSIONS/SUMMARY and the contractor has high confidence in the system Reliability and Maintainability characteristics (through field experience or internal tests for example), then the availability targets can be set at a comparatively high level (in the 95% to 98% range). It is important that the contractor provide feedback to the customer during contractor support planning as to the incremental costs associated with selected levels of availability using the contractor's planned support methods. Further, the Government should consider the operating/training environment (as described in CONCLUSIONS/SUMMARY) in determining availability requirements and chargeability of downtime described below.

KEY ELEMENTS AND CONSIDERATIONS

This section summarizes the key elements and considerations associated with the application of a fixed-price, penalty/incentive contractor support approach with penalty/incentive based on trainer operational availability. It is essential that the concept be considered, planned and defined at the earliest stage of the contract in order for cost savings and avoidance to be realized and to minimize problems in execution of the concept.

## Program Timing and Criteria

The most effective application of fixed-price, penalty/incentive costs savings is on new programs. This is evident from Table 1, which indicates that many of the cost savings are derived from the logistics element requirements in the initial equipment contract. The ideal fixed-price, penalty/incentive, contract support program is one in which several trainers will be installed in one facility to achieve maximum manning productivity. Small, deployable, disbursed, mobile trainers, on the other hand, are not good candidates. In addition, the existing programs being currently supported by the Government or a contractor are not good candidates since the Government's support capability has already been acquired and the costs are "sunk". However, consideration can be given to converting existing military training equipment support facilities to contractor support in cases where the trainer is a large one-of-a-kind, highly-complex unit, or if sources of repair parts through standard Government channel are diminishing. In these cases, contractor support, however, does not offer dramatic cost savings/avoidance but may offer better maintenance personnel stability/skill and more flexibility of support/repair approaches. It is important to recognize in considering converting an existing military support facility to contractor support that there is likely to be an understandable resistance to change on the part of the existing support personnel which may outweigh the less than dramatic cost advantages of converting to contractor support for a fielded system. It is not the intent of this paper to discuss the potentially controversial pros and cons associated with military versus contractor support.

## Chargeability of Downtime

Since the key to the penalty/incentive approach is in the method of calculating the penalty/incentive, it must be specific and clearly defined in contractual terms for calculating chargeability of trainer downtime. The most manageable definition of downtime is as defined by MIL-STD-23991: When the trainer is required for scheduled student training and is not available for that training as a direct result of a system malfunction. Downtime is not chargeable under the circumstances where the trainer is not needed for student training for specific limited periods; or when an apparent malfunction is determined to be the result of improper equipment operation; or when a failure or malfunction is the result of conditions outside of the contractor's control such as facility problems, student misuse, etc.

## On-site Flexibility

While there must be clear contractual definitions, it is important that these definitions do not excessively constrain on-site personnel in adjusting to variations in the training operational environment. Further, if disagreements occur as to downtime chargeability (which experience has shown has been very minimal to date), these disagreements are best handled by referring them through an off-site administrative channel for resolution. Figure 1 is an example of the form used for recording downtime and the conditions at the time of the occurrence. This form has been in use on the existing penalty/incentive T-34C CPT contract.

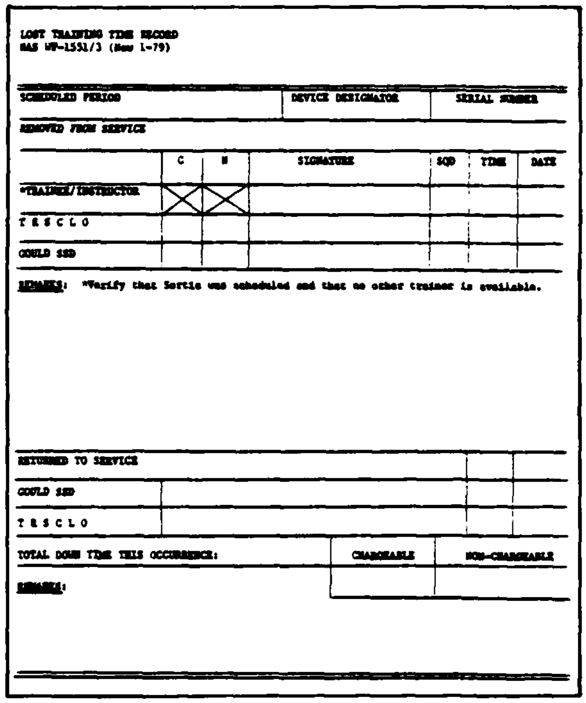


Figure 1. Lost Training Time Record

**Maintenance Personnel Flexibility.** In general, specialization of maintenance personnel is not desirable from a planning viewpoint. Maintenance and support personnel should not be hired or placed on a crew with known skill limitations (e.g., Computer Specialist; Inventory Specialist). Gould/SSD experience indicates that qualified individuals will come equipped with some special skills from prior assignments; and that some specialization is a natural development as support and maintenance activities proceed. In addition, at least one of the senior members of the on-site support team should be designated as the training focal point to insure an on going, optimum mix of skills as maintenance needs dictate.

## Government Maintenance Data Utilization

Use of on-site Government maintenance data capabilities is highly desirable whenever possible. Best advantage is taken when the contractor support team develops a workable Work Unit Code structure for the particular device/equipment being supported and develops unique applications of the local use blocks of the maintenance data collection form as required. In this way, the Maintenance Summary Reports which are developed from data collection system can be used as both deliverable reports to the Government (an additional cost avoidance) and can also be returned to the factory for maintenance and support management purposes.

Additional Trainer Hours

Additional trainer hours must be accounted for in the support contract in the event that weather, student progress, student load, or other variations in training workload require additional hours. Additional trainer hours are normally provided or performed during weekends or if it is critical, during the maintenance shift.

Factory Support

Factory support is a normal part of contractor support. It includes overall support management, budgeting, cost reporting, change review and ECP preparation, reliability and maintainability analyses, vendor or factory repair management, etc. This insures that the on-site effort proceeds in the general direction which was originally envisioned by both the customer and the supporting contractor.

Preoperational Support

This is a particularly important element. It is unlikely that a given contractor will have a fully qualified staff of maintenance technicians automatically available as a result of a development/production effort. The development of this maintenance staff must be a clear-cut element of the contractor support option and must be clearly identified as a support cost for the program prior to the device installation/selloff.

Change Management

Changes are inevitable during any equipment support effort. Again, the key is planning to accommodate change. As shown in Table 1, an important advantage to fixed-price, penalty/incentive contractor support is the cost visibility and control when changes are appropriate. Since under fixed-price, penalty/incentive contractor support, the contractor is reponsible for development and implementation of a change, the support impact costs are identified and included in the ECP not as speculation or prediction but as proposed costs. This insures management, budgeting, timing, and equipment utilization plans are all addressed and accounted for.

The primary sources of change are:

Commercial Equipment. Product improvements (model changes, updates, fixes, etc.).

Reliability/Maintainability (R/M). Changes identified through first-hand trainer operation/utilization (some of these may be submitted at no cost since the contractor would normally propose such R/M changes based upon a payback analysis).

Compatibility Changes. Changes to keep the trainer at the same operational/performance level as the operational equipment being simulated. Compatibility changes are the most common for trainers and contract provisions for them should be specified in the contract to tie the Government, operational equipment manufacturer, and training equipment supplier into the same configuration management process.

## TRANSITION PACKAGE

In planning for any form of contractor support, it would be judicious for the Government to address the possibility of a change in support responsibility at some point in the Operation and Support (O&S) phase of a program. Even though such changes would be unlikely, they should be considered to avoid the negative support impact of contractor's not bidding for support contracts, unexpected or unjustified cost increases, or other major changes in support philosophies.

Therefore, Gould/SSD has developed the "Transition Package" concept under which the contractor includes a fixed-price option to allow a smooth turnover from one contractor to another, or to Government personnel. This option should include the minimum necessary logistic elements to insure a smooth transition. These elements would include as a minimum:

- Maintenance drawings.
- Provisioning documentation.
- Software documentation.
- Technical manuals.
- Special purpose tools and test equipment.
- On-the-job-training.

As part of the contract, a transition plan should be included in the basic contract as a deliverable item to the Government, to be updated on a regular basis with sufficient scope and depth to insure an orderly transition should the need occur. The format would be similar to an Integrated Logistics Support Plan.

A penalty clause should be included in the contract to preclude the contractor from placing the Government in an untenable sole source situation, in that the contractor must provide the Government sufficient time to transition the device support from one contractor to another, or to Government personnel as the case may be.

The specific contents of the transition package should be discussed and agreed to at the same time as contractor support (or a contractor support option) is exercised. This timing is essential to insure that proper mix between the requirements of the contractor support contract and the necessary (but not duplicative) elements of the Transition Package.

## COST PROFILES AND COMPARISONS

Figure 2 indicates typical cost profiles for the alternatives discussed in this paper. The cost profiles shown are a summary level consolidation of cost information derived from the previously mentioned programs and the estimated savings associated with FPPICS. Since each

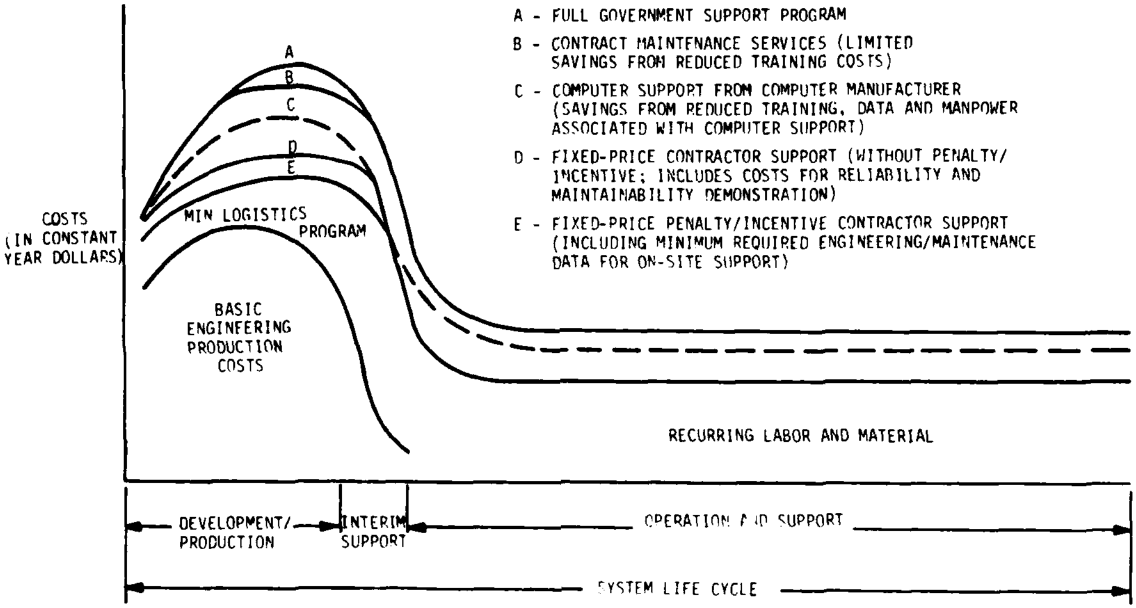


Figure 2. Comparative Cost Profiles for Contractor Support Alternatives (when applied at program initiation for a typical simulator program).

program contains its own unique requirements, the profiles have been averaged so that they reflect a "typical" trainer program and are representative of the cost differences at the system level. Of course, any such analysis of this type is inherently subject to analytical judgment and to variations in implementation. The fixed-price, penalty/incentive cost savings approach achieves the maximum support savings when applied at program initiation. The extent of savings is dependent primarily on both what the conventional support requirements would start with (i.e., LSA or Functionally Oriented Technical Manuals would increase the conventional support basic costs), as well as the cost assumptions used for salary/overhead rates for Government maintenance personnel (which may vary according to the extent of Government overhead which is allocable to the Government support direct costs).

## CONCLUSIONS/SUMMARY

Based on the discussion above, fixed-price, penalty/incentive contractor support offers significant advantages in terms of cost savings/avoidance, availability and proficiency of support personnel, and "insured" equipment performance for training. To pursue this approach in general and/or for a particular contract, the following recommendations are made:

### Description of the Operating/Support Environment

It is important that the customer describe specifically the intended equipment utilization methods, utilization rates, operating hours, student flow, team training versus individual training, the role of the instructor/operator in system maintenance and any other application unique information.

### Development of Model Contracts

The Government Procurement Agencies should develop a "standard" for contractor support options/contracts including planning checklists, standard contract provisions, and clauses, etc., covering the issues in this paper and any other applicable areas so that the management learning curve is realized in the tailored application of contractor support approaches. The "standard" should be developed jointly between military training procurement agencies and industry by preparation of initial drafts, conferences, interim guidelines, and, where appropriate, trial applications.

### Similarities Between Penalty/Incentive Support and Existing Commercial Equipment Support

It should be noted that most commercial equipment suppliers (e.g., commercial computer manufacturers) offer contractual support (or "customer service") as a matter of routine. And as described above, commercial support of computers is being considered more and more for training equipment computers when the appropriate conditions exist. Since many military simulators are used in a predicatble, fixed-facility or institutional application and since they make use of more and more commercial equipment instead of operational equipment, the parallels and commonalities between commercial support and contractor support from the trainer manufacturer should be used (where applicable) as a guide and as an experience base in applying contractor support to training equipment.

## Budgeting

The military budgeting process should also be reviewed as a part of a fixed-price, penalty/incentive, cost savings implementation program, and to pursue contractor support in general. Since the fixed-price, penalty/incentive cost savings approach involves lowering acquisition costs/budgets, a vehicle for transferring the released ("avoided") acquisition costs to budgets for contractor support (preoperational support and operational and maintenance) should be established. At the same time, the follow-on operation and maintenance budgets should be established as early as possible to insure that the contractor support approach is viable and funded throughout the operational and support phase of a program.

## Tailored Application

As mentioned previously, new acquisition programs are the best candidates for application of this concept. Once a "standard" for contractor support is developed, its application should be tailored to new programs as they are identified. In this way, the full range of advantages of the fixed-price, penalty/incentive, contractor support approach can be realized while at the same time avoiding the resistance to the approach inherent in converting training equipment support programs to contractor support.

## REFERENCES


(1) T-34C CPT (Device 2C42) Contractor Support Contract; NAVAIR Contract Number N00019-78-C-0339, 4/28/78.

(2) Device 20B5, Perry Class (FFG-7) Pierside Combat System Team Trainer Solicitation; N61339-79-R-0044 (31 August 1979); NTEC.

(3) Chief of Naval Operations Ser 596/337687 12 April 1979; Subject: Navy Management Plan for Chief Naval Air Training Flight Simulators Supported by Contractor Maintenance.

(4) Minutes of NTEC Government/Industry TPR/RFP ILS Improvement Strategy Meetings, 24 January 1980 and 11- 12 March 1980.



## BIOGRAPHICAL SKETCH

Mr. Scaramella is Director of Integrated Logistics Support Engineering for Gould Inc., Simulation Systems Division. Mr. Scaramella has been in the Logistics field for over twelve years including seven years in the training community and participated in the initial development of the T-34C CPT contractor support concept. He is familiar with contractor maintenance and support of trainers from both Government and Industry perspectives.

# COST EFFECTIVE ACQUISITION OF CONTRACTOR MAINTENANCE TRAINING

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## ABSTRACT

This paper suggests that contractor maintenance training acquisition procedures used by Government are often not cost effective and suggests a paradigm for the development of acquisition procedures which will increase training effectiveness and reduce costs. Government often levies excessive and unnecessary restrictions on contractor by insisting that certain military standards and data item descriptions be followed even in those circumstances when such standards are both inappropriate and undesireable. This approach results in increased training acquisition costs.

## INTRODUCTION

Contractor maintenance training courses for newly procured training devices are acquired for one reason only: to ensure that qualified personnel will be available to maintain the device throughout its life cycle. These courses must achieve an appropriate balance of various factors such as device maintenance concepts, performance objectives to be attained, and availability of training funds. Ideally, a course graduate will have the ability to effectively diagnose and isolate faults and repair the device within the specified mean downtime limits. The training acquisition program also procures training documentation and curricula to be used for retraining in the out years.

In the past few years, major forces have impacted heavily on the training device world. The scarcity and cost of fuel have caused an increased demand for training devices to replace training normally conducted in operational situations. To meet this need, more complex and sophisticated training devices are being developed. As technology advances, maintenance concepts change in an attempt to keep pace. Concurrently, it has become apparent that the input skill level of trainees is continually declining. Training funds are always in the vanguard of budget cuts. Given these factors as more or less permanent fixtures for the foreseeable future, it is imperative that cost effective, dynamic maintenance training acquisition concepts be developed if the training device community is to remain responsive to its overall mission.

## PROBLEM ANALYSIS

Evidence which suggests that current maintenance training acquisition procedures are not cost effective can be traced to one major underlying factor: excessive Government regulation of industry. Several high level directives have been issued in an attempt to deal with this problem, four of which are expressly germane to the maintenance training acquisition process. The Defense Acquisition Regulations (DAR) set forth the basic legal doctrine defining the role of Government and contractor relationships. (1) Office of Management and Budget (OMB) Circular A-109 Major Systems Acquisitions further defines these roles and explicitly recommends that Government establish system performance objectives and allow the contractor to develop detailed design and training objectives. (7) The policies of OMB Circular A-109 are further explicated in OMB Curcular A-76, Policies for Acquiring Commercial or Industrial Products and Services for Government Use. (6) Secretary of the Navy Instruction (SECNAVINST) 4200.27A Proper Use of Contractor Personnel clearly defines the proper role of contractor personnel. (9)

In spite of these and other policy documents and legal prohibitions, current acquisition procedures continue to regulate almost every step of a contractor's maintenance training development efforts. In the initial phases of procurement, detailed overly specific Requests For Proposal (RFP) limit the creativity and resourcefulness of the contractor. (10) Once the contract has been awarded, the administration of the maintenance training acquisition element often veers away from the spirit and the letter of the directives cited above. Both of these situations are results of the current maintenance training acquisition philosophy, which has evolved into a rigidly structured process of constant control and monitoring of the contractor's efforts from program conception to contract conclusion. Government personnel from the functional areas of engineering, management, logistics, contracting, and training continually tell the contractor what and how much training is required, how to develop the training curriculum, how to write curriculum data items, and what instructional procedures will be followed. Particularly in the curriculum development process the contractor is bound to procedures outlined and delineated in a plethora of regulations and instructions. The entire training course and curriculum development process is tied to the contents of the Military Standard governing contract training programs (MIL-STD 1379A) and various Data Item Descriptions (DIDs). (2) These standards specify that the format, content areas, and virtually all other facets of the curriculum associated documents will be developed in accordance with highly structured curriculum development models.

However, highly structured models are not panaceas for all curriculum development efforts and problems. While an instructional system development process provides excellent curriculum development guidelines and procedures for efforts on training courses of a continuing or "pipeline" nature, this process is not always appropriate for developing curricula for what are essentially one time factory training courses. Curriculum development utilizing rigidly structured procedures and models requires a substantial expenditure of time, effort, and money. Such expenditures can be justified for a "pipeline" type training course; they cannot be justified for a course that will be presented only one or two times during a device life cycle even if quality products are received.

Unfortunately, quality products are rare. A large number of curricula are accepted by Government because they meet all the legal requirements of the contract, not because they are of high quality. While in the process of preparing and responding to RFPs, neither Government nor industry pays proper attention to the difficult nature of applying the instructional systems development process specified by MIL-STD 1379A. As a result, contractors often misjudge the effort required to meet standards specified by MIL-STD 1379A and associated DIDs. A recent study has partially documented some of the curricula development problems encountered by a professional training development firm using these Government mandated procedures. (3) These problems and others can reasonably be expected to pose major concerns for hardware oriented contractors, particularly those who rarely employ personnel with instructional systems development experience. Contractors usually appoint engineers, technical writers, publication specialists, or personnel from a public school or university background to head and staff their training departments.

The acceptance of mediocre and marginal quality curricula is also influenced greatly by the delivery schedule of curricula data items. These items are normally delivered toward the end of the acquisition cycle. Shrewd contractors realize that at this stage of the cycle, hardware oriented Government program managers are growing weary of problems, especially if device delivery has been delayed one or more times and cost overruns have occurred; they are anxious to close the contract. All too often, various pressures cause curricula data item discrepancies, which threaten further delays, to be inadvertantly overlooked.

Over the years, various management policies have evolved which seldom allow training acquisition personnel to simply reject an unsatisfactory product; a detailed justification explaining why the product was rejected must be provided. Astute contractors are aware that if these detailed justifications are not provided, low quality curricula data items can be produced at a sizable cost savings. Once detailed comments are provided, all the contractor need do is incorporate these comments into his own format and resubmit. This editing function constitutes a very time consuming process for training acquisition personnel. Situations thus tend to develop wherein Government personnel provide detailed instruction in curriculum development prior to the delivery of final data items simply to preclude becoming a contractor's proofreader and editor.

As a result, in many instances, training acquisition personnel perform a significant portion of the contractor's work in order to receive an acceptable, quality product. This process keeps these personnel from performing more important functions, such as maintenance training needs analysis, development of performance objectives, and training evaluation. It is also in direct violation of various policies and directives.

Still another problem inherent within the current training acquisition philosophy is the procurement of unnecessary curriculum data items. The typical curriculum acquired for a maintenance training course consists of a Training Course and Curriculum Outline, an Instructor's Guide, a Student Guide, Audio Visual Aids, Tests, Evaluation Forms, and an On-The-Job Training Handbook. The average cost for these data items is $64,000. with an upward range of well over $250,000. Yet it is seldom questioned whether all of these items are actually required to achieve an acceptable maintenance training course.

Curriculum data items produced for a maintenance training course consist of maintenance documentation packaged in an instructional systems format. This same documentation is also delivered under another contract line item. Since both line items are priced out as original development effort, in effect Government is paying twice for one product, namely technical maintenance documentation.

As an example, an On-The-Job Training Handbook is little more than a guide and a supplement to device maintenance documentation. Still, Government pays up to $65,000. and over to acquire On-The-Job Training Handbooks. Perhaps this expenditure might be justified if Instructor

Guides, Student Guides, Audio Visual Aids, and Text materials were not also acquired. Some Government agencies are beginning to deal with overprocurement problems such as these by establishing Maximum Data Lists and Data Review Boards. Although such tactics produce limited results, they are in effect well meaning attempts to "fix" a system that appears to require a major overhaul. There is no rational justification for procurement of all these curriculum items in addition to the required maintenance documentation.

Further, contracts normally require that the person designated as the maintenance training course instructor be a member of the team that develops maintenance and other device documentation. During this process, the instructor necessarily has to compile notes, diagrams, and other materials that will be used in teaching the course. Prior to the application of an instructional systems development process to almost every curriculum development situation, effective maintenance training courses were conducted using the instructor's personally prepared lesson plans, professional knowledge and expertise, and the maintenance documentation.

The only logical rationale for paying the contractor to restructure all of this technical knowledge and information into a specific instructional systems format appears to be that the curriculum data items will be required for retraining efforts in the out years. However, this rationale does not hold up under close scrutiny. By the time retraining is required either device modifications have made the training material obsolete or the material has been lost. Although one or two curriculum data items may be used in retraining, the entire curriculum package will be used only once or twice in a fifteen year period, if used at all. More often than not, situational requirements dictate that personnel who conduct retraining develop their own materials and methods to meet current needs. In essence, a qualified instructor and a well developed and up to date maintenance documentation package are the only elements required to conduct formal retraining courses. Moreover, individualized learning programs such as Technical Hands On Training (THOT) packages are finding greater acceptance and application in the retraining effort. Since Government personnel have the ability to develop THOT type programs from high quality and complete maintenance documentation, the requirement to procure fully developed, rigidly formatted curriculum is obviated.

Another dubious cost factor can be found under the heading "Instructor Preparation Time." As noted earlier, the instructor is normally required contractually to be a member of the team which develops maintenance documentation. Still, contractors insist upon an instructor preparation time within a ratio of 2 to 6 times course length. This means that if a maintenance course is scheduled to be 6 weeks long (240 hours), a contractor may submit charges for preparation time that range from 480 hours up to 1440 hours. At an average conservative rate of \$35. an hour cost to Government, this translates into a price range of \$16,800. to \$50,400. for preparation time. Since the instructor is required to be intimately familiar with the device under the terms of the contract, it would appear that in many instances Government is charged twice for the same product, namely the instructor's knowledge of device operation and maintenance procedures.

No satisfactory explanation has been advanced to explain why, after spending between 9 and 18 months as a member of the team which develops maintenance documentation and curriculum data items, an instructor would require anywhere from 12 to 36 weeks to prepare to teach a 6 week course. This reasoning is even more incongruous when it is realized that at least 3 of the 6 weeks will be devoted to student hands-on training in the laboratory, with the instructor serving in an observer/advisor capacity. This leaves only 3 weeks of actual instruction time for which preparation is required.

## DATA ANALYSIS

Maintenance training acquisition costs are defined as dollars provided to the contractor to develop and present maintenance training. These costs include the cost of instructor services and development costs for curriculum data items. Because of the infinite number of variables present in maintenance training acquisition programs which extend over a period of two to three years, and because of the variations in individual contracts, precise data, especially for curriculum data items acquisition, are not available. However, from the accessible data, it is possible to ascertain that maintenance training costs are steadily increasing.

The periods chosen for this study coincide with the introduction of instructional systems development models to the maintenance training acquisition process in 1973 - 1974, and the issuance of MIL-STD 1379A in 1976. Although a portion of the increased costs of training acquisition can be attributed to inflation, the data strongly suggests that inappropriate curriculum development standards and over-regulation of the contractor's development efforts have contributed greatly to this increase.

Curricula data items are not normally priced separately in a contract but by lot with other written materials. Available information indicates that for a contract in the \$2,000,000. range, the average cost of training data items is \$65,000. or approximately 3.3% of the total contract price. As has been shown earlier, many of these data items are unnecessary, thereby adding to the overall non-cost effectiveness of the maintenance training acquisition process.

A cost analysis of Instructor Services (preparation, presentation, and other associated costs) indicates a major increase in the weekly cost of maintenance training beginning in 1974. The average cost per week for the period 1969 through 1973 was $2700. while for the period 1974 through 1979, the average cost per week was $5100. This represents an increase of 93%. A second comparison shows that the average cost per week for the period 1974 through 1976 was $4600., while for the period 1977 through 1979, costs averaged $5700. per week, a 24% increase. A comparison of the average costs per week for the 1969 - 1973 period with the 1977 - 1979 period shows an increase of 111%.

To examine maintenance training costs from a different perspective data was gathered from a random sample of 30 maintenance training acquisition programs; 15 from the period 1972 - 1975, and 15 from the period 1976 - 1979. The data gathered from the first period were used in establishing a baseline with which to compare the costs of procurements under MIL-STD 1379A, which was issued in 1976.

A summation of the gathered data indicates that in the period 1972 - 1975, 220 weeks of maintenance training were procured. Total procurement costs for the 15 training programs were:

(Costs shown in millions of dollars)

| Contract | Hardware | Maintenance Training |
|---|---|---|
| 31.8 | 23.4 | .70 |

In comparison, during the period 1976 - 1979, 156 weeks of maintenance training were procured. Total procurement costs for the 15 training programs were:

(Costs shown in millions of dollars)

| Contract | Hardware | Maintenance Training |
|---|---|---|
| 27.9 | 20.8 | .92 |

The average cost per maintenance training hour for the 1972-1975 programs was $80. For the post 1975 programs the average cost per maintenance training hour was $147. This is an increase of $67. or 84% per training hour.

Because of the problems involved in attempting to correct for the effects of inflation, data were primarily analyzed as ratios of maintenance training costs to total contract and hardware costs:

| | Hardware to Contract | Maint. Trng. to Contract | Maint. Trng. to Hardware |
|---|---|---|---|
| Baseline 1972-1975 | 73.5% | 2.2% | 3.0% |
| Current 1976-1979 | 74.9% | 3.3% | 4.4% |

During the 1972 - 1975 period maintenance training costs were 2.2% of total contract costs. During the 1976 - 1979 period, maintenance training costs rose to 3.3% of the total contract cost, an increase of 50%. The maintenance training to hardware cost ratio has also risen by 47%, although hardware costs have increased by a ratio of only 1.9%. Results similar to these have been found in a separate study recently conducted on 20 other maintenance training programs. (4)

The last decade has seen advances in maintenance aids such as software diagnostics for troubleshooting, more modularized equipment which calls only for isolation to board level, and card testers which expedite and facilitate component isolation. Still, maintenance training programs have become more expensive both in true dollar value and as a percentage of contract cost.

## RECOMMENDATION

Fresh thinking is sorely needed in the general area of life cycle device maintenance and the specific area of maintenance training if the above trends are to be reversed. Although many arguments can be made in support of current methods of maintenance training acquisition, little data exists to support these arguments. It must also be remembered that cost effectiveness and training effectiveness are not synonomous terms. (8) Even if it could be proven that current acquisition procedures are effective, this does not exclude the very strong probability that other procedures may be equally effective and may cost considerably less.

Contractor developed maintenance training may be acquired more cost effectively through the implementation of a Criterion Referenced Systems Approach (CRSA) to maintenance training acquisition. This approach is based on three premises:

a. maintenance training is an integral part of device procurement, and the contractor should be tasked with the full and total responsibility for providing training that will produce qualified device maintenance personnel.
b. given the proper motivation, contractors can acquire the resources and expertise required to provide high quality maintenance training in a cost effective manner.
c. Government can provide this motivation by stipulating in the contract that a significant portion of total payment will be withheld until satisfactory training is received and by allowing the contractor to accomplish this without the burden of excessive Government restrictions and directions.

CRSA in the training acquisition process consists of three components: INPUT-PROCESS-OUTPUT. Neither the CRSA model nor the CRSA concepts are new or unknown in the training field. What may be unique is that CRSA is based on the premise that if Government furnishes the required input and defines the required output, and holds industry totally accountable for the process, high caliber, cost effective maintenance training will result.

The INPUT component is the responsibility of Government. Skill and knowledge profiles have been developed for each Navy rate and rating. It is up to Government to determine from what skill and knowledge level the contractor must start developing his training. Prospective students should be pretested to ensure that Government and contractors are aware of the actual skill and knowledge levels of these students. If remediation is required, it may prove more cost effective to procure remedial training through some other source than to have the contractor develop a longer training course to accomodate deficiencies in student input levels. This component also contains performance objectives which have been derived from a training requirements analysis. (11) Again, it is Government's responsibility to determine what level of performance is required of a course graduate and to define these requirements clearly and succinctly.

The ultimate cost effectiveness of the training will depend in large part on what skill and knowledge levels have been selected, on how well training requirements have been analyzed, and on how skillfully performance objectives have been constructed. In effect, Government is establishing criterion referenced inputs and certifying that the contractor should base his cost proposal on these inputs. If for some reason Government should deviate from these inputs, the contractor can easily measure the deviation and rightfully claim a commensurate amount of consideration.

The PROCESS component is the sole responsibility of the contractor. After receiving all the required input data, the contractor is tasked with the total freedom to develop a training curriculum that will satisfy the performance objectives. Since satisfactory completion of training will be based on criterion referenced performance objectives and measurements, it becomes the responsibility of the contractor to develop an accurate cost proposal. If the contractor underestimates the effort involved, he will no longer be able to claim his problems have been caused by Government demands and changes, as currently occurs all too often. Since there will be no provisions for "get well" clauses at Government's expense in the contract, contractor mistakes or ineptitude will affect only the contractor. He will still be required to provide what he said he would or suffer the loss of a significant portion of the overall contract price.

It is in this component of the CRSA that strict adherence to the directives and instructions cited earlier is required. SECNAVINST 4200.27A is specific in defining the required Government/contractor relationship:

> The Government may...obtain the (required) work by contract, providing two conditions are met: (1) the contract itself must ask for the finished product, only, and (2) the contract must be administered in such a way that control and supervision over the work and discretion as to the techniques which will be used remain solely with the contractor....

The intent of this statement is made explicit in the very next sentence.

> ...In other words, if the Government wants a building painted (or personnel trained), it defines the job, lets the contractor paint the building (train the personnel) as he sees fit, and then accepts it or rejects it solely on the basis of whether the completed job meets the contract specification....

The OUTPUT component is the responsibility of Government, which must determine what it expects the student to be able to accomplish upon completion of maintenance training. These expectations must be stated in terms of effective performance as established by criterion based performance objectives. In order to accomplish this, a thorough maintenance training requirements analysis must be commenced as soon as the engineering specifications are formulated. From this analysis, functional training specifications are written by Government. These specifications set forth the performance objectives and assessment methods which Government intends to use to accept or reject the contractor's training effort.

The performance objectives and methods of assessment become part of the input component. Once these items are defined, Government is able to write an RFP which will enable contractors to develop effective, competitively priced cost proposals. After a proposal has been accepted and a contract awarded, the data therein is used to develop a definitive assessment design and specific performance measurements with which to measure the contractor's maintenance training performance.

The preferred method of assessment is a comprehensive performance examination which might also serve as a maintainability demonstration. Such an assessment instrument would assure that the trainees are actually capable of fully maintaining the device to the level required by the contract. If a written assessment is deemed desireable, the Solomon design is an excellent method of determining the value of the instruction received in comparison to the general knowledge that the trainee may posess from experience or by association with other training devices.

## SUMMARY

The rising costs of contractor developed maintenance training are decreasing the cost effectiveness of current training acquisition procedures. Given the austere funding climate of the predictable future, this situation is intolerable. Preliminary research indicates that several underlying causes contribute to the unwarranted escalation of maintenance training costs. When these causes are examined, it becomes apparent that adherence to inappropriate acquisition policies results in inadequate definition of needs, improper utilization of Government personnel, unnecessary procurement of data and services, and loss of contractor ingenuity and resourcefulness.

Obviously, there is no one perfect method which will ensure cost effective acquisition of maintenance training. The method recommended in this paper is just as susceptible to inept application as is the current method. However, the authors believe that given equal amounts of conscientious attention by maintenance training acquisition personnel, the Criterion Referenced Systems Approach will prove more cost effective than have the current methods of maintenance training acquisition.

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# COST EFFECTIVENESS IN DATA MANAGEMENT
# OR
# WHY BUY MORE THAN YOU NEED

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## ABSTRACT

This paper suggests that data management acquisition procedures used by Government are often not cost effective. All sorts of military standards are deemed "the thing" when contractors' formats would suffice at a substantial savings. Data management acquisition procedures need an overhaul. The Naval Training Equipment Center (NAVTRAEQUIPCEN) has developed a Recommended List of Approved Data Item Descriptions (DID's) and DID numbers for a major weapon buy. This list must be tailored to the requirement. In addition, Data Management, Technical (DAMTEC), an automated system for tracking the Contract Data Requirements List (CDRL) items in contracts, has been developed to monitor the progress of the deliverable data and to serve as a data bank for use by project team members. This data bank provides cost comparison information based upon cost of data previously bought for various training equipment.

## INTRODUCTION

During the 1960's the National Aeronautics Space Administration (NASA) bought trainloads of data, and developed a slide rule for assessing its cost. Just as NASA was concerned by the mounting cost of documentation, we at NAVTRAEQUIPCEN are also concerned. Sometimes it appears that all Government wants, or is looking for, is more and more technical data. "Not so," says NAVTRAEQUIPCEN. In 1979 the Center sharpened its data management pencil and "managed" to delete 31 items from an 81-item list of data for larger procurements without weakening support to the related training equipment. Cost savings have been dramatic.

### Definition of Technical Data

According to DOD, technical data are "recorded information used to define a design and to produce, support, maintain, or operate items of defense material." These data may be recorded as graphic or pictorial delineations in media such as drawings or photographs; text in specifications or related performance or design-type documents; in machine forms such as punched cards, magnetic tape, computer memory printouts; or may be retained in computer memory. Examples of recorded information include engineering drawings and associated lists, specifications, standards, process sheets, manuals, technical reports, catalog item identifications, and related information. These technical data are identified on a DD Form 1423, Contract Data Requirements List (CDRL), if the contract requires delivery of the data.

### Data Cost Factors

The contractor has to prepare certain data to satisfy the design, development, testing, and production aspects of the contract regardless of the deliverable data requirements placed on the contract by the government. Knowing that much of the data required by the government are basically the same as that prepared by the contractor for his own use in satisfying the contract, DOD, in conjunction with Aerospace Industry Association, developed what is known as the "over-and-above" concept.

This concept in action requires the contractor to include in his estimated selling price on each specified data item, that portion of the development/preparation data effort expended by him to solely satisfy the government requirement for a deliverable data item.

This estimated selling price to the government also includes General and Administrative (G&A) costs, overhead, and profit. Under the "over-and-above" concept the estimated selling price is contingent upon whether or not the contractor had to prepare the data for his own use or solely to meet the government requirements.

Current DOD policy identifies four pricing conditions, known as "Price Groups," which the contractor utilizes under the "over-and-above" concept. They are summarized as follows and then defined in the narrative.

| Group | Essential to Performance of Contract | Added Effort Required | Price |
|---|---|---|---|
| I | NO | YES (100%) | YES |
| II | YES | YES | YES |
| III | SOME | SOME | YES |
| IV | NONE | NONE | NO |

Group I - Data which the contractor prepares to satisfy the Government. The contractor does not need this type of data to perform the rest of the contract. Price would be based on identifiable direct costs, overhead, and profit. Technical manuals prepared for government use are an example. (Engineering drawings generally are the source material for technical manuals. The cost of developing these drawings is not a cost of producing the manuals.)

Group II - Data essential to contract performance which must be reworked or amended to conform to government requirements. The price for data in this group would be based on the direct cost to conform the original data to government needs and to deliver it, plus allocable overhead and profit. Much of the data purchased is from this group.

Group III - Data which the contractor must develop for his own use and which require no substantial change to conform to government requirements regarding depth of content, format, frequency of submittal, preparation, and quality of data. Only the cost of reproducing, handling, and delivery, plus overhead and profit, are considered in pricing data in this group. An example of the kind of data to be categorized as Group III would be DOD-D-1000 Level 1 drawings used in the manufacturer's normal plant functions. Level 1 drawings are those drawn to company standards.

Group IV - Data which the contractor has developed as part of his commercial business. Not much of these data are required and the cost is insignificant. The item is coded "no charge." Example: A brochure or brief manual developed for commercial application which will be acquired in small quantities, the added cost is too small to justify the expense of computing the charge that otherwise would go with the acquisition.

Data, Data, Everywhere? -- What to Buy?

Prior to 1979, NAVTRAEQUIPCEN was being inundated with data. On a typical major procurement, "minimum" data requirements totalled 81 items. The Center's Data Management Officer chaired a data review board which screened and rewrote all Data Item Descriptions (DID's) to reduce cost-driving requirements, and encouraged use of contractor's format. The list was reduced to 50 items. The immediate impact was to cut the cost of data on a single procurement from $436,223 to $309,709.83 for a savings of $137,513.17. The new "Recommended Data List" is shown in figure 1. It is a maximum requirement list for a major training equipment procurement, and only selected DID's are expected to be used to acquire necessary data; tailoring should take place throughout the system/equipment life cycle.

Exhibit A - Engineering Data (Hardware)

| | | |
|---|---|---|
| 1. | Trainer Engineering Design Report | UDI-S-25591A |
| 2. | Trainer Test Procedures | UDI-T-25594A |
| 3. | Trainer Facilities Report | UDI-P-25579 |
| 4. | Trainer Photographs | UDI-E-25559 |
| 5. | Trainer Slides | UDI-E-25560 |
| 6. | Trainer Mockup Report | UDI-E-25565 |
| 7. | Trainer GFE Report | UDI-P-25581 |
| 8. | Trainer Artist Sketch | UDI-E-25562 |

Exhibit A - Engineering Data (Software)

| | | |
|---|---|---|
| 9. | Software Development Plan (SDP) | DI-A-2176/MOD |
| 10. | Specification, Program Performance (PPS) | DI-E-2136/MOD |
| 11. | Interface Design Specification (IDS) | DI-E-2135/MOD |
| 12. | Computer Program Test Plan | DI-T-2142/MOD |
| 13. | Computer Program Test Procedures/Reports | DI-T-2144/MOD |
| 14. | Program Design Specification (PDS) | DI-E-2138/MOD |
| 15. | Data Base Design Document (DBDD) | DI-S-2140/MOD |
| 16. | Program Package Document (PPD) | DI-S-2141/MOD |
| 17. | Program Description Document (PDD) | DI-S-2139/MOD |
| 18. | Operator's Manual | DI-M-2145/MOD |
| 19. | Computer Software Trouble Report (STR) | DI-E-2178/MOD |
| 20. | Software Quality Assurance Plan | DI-R-2174/MOD |
| 21. | Software Configuration Management Plan | DI-E-2175/MOD |
| 22. | Software Change Proposal (SCP) and Software Enhancement Proposal (SEP) | DI-E-2177/MOD |

Exhibit B - Administrative Data

| | | |
|---|---|---|
| 23. | Trainer Technical Progress Report | UDI-A-25602A |
| 24. | Cost Schedule Status Report | DI-F-6010 |

Exhibit C - Provisioning Data

| | | |
|---|---|---|
| 25. | Provisioning Parts List (PPL) | DI-V-7002 |
| 26. | Provisioning Forms | |
| 27. | Provisioning Parts List Index (PPLI) | DI-V-2022/MOD |
| 28. | Supplementary Provisioning Technical Documentation (SPTD) | DI-V-7000 |
| 29. | Provisioning and other Procurement Screening Data | DI-V-7016B |
| 30. | Repairable Item List (RIL) | DI-V-7005 |
| 31. | Post Conference Provisioning List (PCPL) | DI-V-2172 |
| 32. | Interim Support Item List (ISIL) | DI-V-7006 |
| 33. | Recommended List of Maintenance, Test and Support Equipment (MT&SE) | DI-V-5275/MOD |
| 34. | Design Change Notice (DCN) | DI-V-7009 |
| 35. | Inventory/Utilization Data Report (IUDR)* | UDI-V-25513 |

**Exhibit D - Maintenance Data**

| | | |
|---|---|---|
| 36. | Reliability/Maintainability Status Reports | UDI-R-255844/ UDI-L-25572A |
| 37. | Nonstandard Part Approval Requests | DI-E-7028 |
| 38. | Integrated Logistic Support Plan (ILSP) | UDI-L-25622B |
| 39. | Training Equipment Summary | UDI-L-25510 |
| 40. | Contractor Field Service Reports | UDI-L-25514C |
| 41. | Drawings, Engineering and Associated Lists | DI-E-7031/MOD |
| 42. | Trainer ECP Summary | UDI-E-25603 |
| 43. | Training Device Inventory Record | UDI-L-25578A |

**Exhibit E - Publications Data**

| | | |
|---|---|---|
| 44. | (a) Manual, Technical, Functionally Oriented Technical Manual (FOTM) For Training Devices** | UDI-M-25597B |
| | (b) Manual, Technical, Operation and Maintenance Instructions** | UDI-M-25575 |
| 45. | PMS Documentation | UDI-L-20304A |
| 46. | Manual, Technical, Commercial Standard | UDI-M-25576 |
| 47. | Vendor Equipment Data Updates | UDI-M-25700A |

**Exhibit F - Training Data**

| | | |
|---|---|---|
| 48. | Outlines, Training Course Curriculum (Option 1 only) | DI-H-2026 |
| 49. | Guides, Instructor/Lesson-Training Courses | DI-H-2073 |
| 50. | Audiovisual, Aids, Master Reproducibles and Review Copies Training Equipment and Training Courses | DI-H-2122 |
| 51. | Test, Measurement of Student Achievement | DI-H-2033A |
| 52. | Forms Evaluation - Student & Training Course | DI-H-2165 |
| 53. | Handbook, Instructor's Utilization Simulation Equipment | DI-H-2028A |
| 54. | Guides, Students - Training Courses | DI-H-2102A |

*Not required if 3M reporting invoked.
**Only one of these items is used.

Figure 1. Recommended Data List

DAMTEC

To monitor the progress status of these DID's, DAMTEC, an automated data processing (ADP) system was developed. This unique ADP application monitors the progress of the deliverable data items identified on DD Form 1423's in the contract. DAMTEC serves as a data bank for use of project team members making them aware of the total picture. In addition, DAMTEC alerts the team when the delivery of a CDRL item is due, or when the delivery of a CDRL item is overdue. This system provides up-to-date and accurate access to all information related to contract technical data. On a weekly basis, one report automatically flags those contract/item numbers that have potential slippage of milestone dates. The DAMTEC Element Dictionary consists of 33 data elements, nine of which are automatically extracted from two other NAVTRAEQUIPCEN computerized systems, the Technical Program Control System and the Contract Status System. In this way, the Data Specialist need not duplicate effort by inputting like data which is already stored in the computer.

DATA ELEMENT DICTIONARY

ACCEPTANCE DATE
APPROVAL CODE
ACTUAL RESPONSE DATE
CANCEL DATE
COMPLETION DATE
CONTRACT AWARD VALUE
CONTRACT NUMBER
CONTRACTOR NAME
CONTRACT STATUS
CONTRACTOR RESPONSE DUE
DATE RECEIVED
DUE DATE
DEVICE NOMENCLATURE
DEVICE NUMBER
DID TITLE
ELEMENT MANAGER
EXHIBIT IDENTIFIER
FREQUENCY
FINAL
GOVERNMENT RESPONSE DUE
IF ITEM WAS ACCEPTED/ REJECTED
ITEM DATA COST
ITEM NUMBER
LATEST MILESTONE DATE
NATIONAL STOCK NUMBER/ LOCAL STOCK NUMBER
OBLIGATION ACTUAL DATE
PRELIMINARY
RECORD CHANGE DATE
PROGRAM CODE
REMARKS
TASK NUMBER
TECHNICAL DATA SPECIALIST
TECHNICAL OFFICE

From the Data Element Dictionary comes the "DAMTEC Data Item Status Report by Contract Number". This report selects all records on the DAMTEC Data Base, except those coded "C" (closed) in Contract Status data element. Another report, "Milestones Due/Overdue," selects all records with the latest milestone past due or due within seven days of the "as of" date on the report. One of the most used reports is the "Data Item Status Report by Technical Office and Element Manager". The element manager has a composite of what line items he is responsible for reviewing and, if it has already been received, the response/review date he must meet. AD HOC reports, selecting any imaginable combination from the Random Select Report Module, can be requested by properly querying the data bank and asking for contract number sequence, device number sequence, DID sequence, etc. As indicated above, the primary purpose of DAMTEC is to serve as a progress monitoring tool. However, this data bank, because it can store and report data item costs, also serves as an excellent guide in determining item "should costs", and otherwise aid in tailoring requirements for new procurements. Although DAMTEC has been in operation for less than a year, it has been praised by project team members and element managers. New uses for DAMTEC are constantly being discovered, and NAVTRAEQUIPCEN sees it growing into a bigger and better project management tool.

## CONCLUSIONS

Guidelines should be developed for selecting tailoring, and applying specifications and standards, data requirements, and management systems to assist personnel.

Cost-driving requirements of specifications should be identified and tailored prior to requesting proposals.

Data banks should be established and used in modifying requirements for new procurements.

Industry should assist the Government in identifying the cost-driving requirements of present DID's and standards imposed on Government procurements.

Industry should automatically provide alternate proposals on all RFP's to indicate how contractor format or other alternatives can be used to reduce proposal cost with no loss in technical information being provided.

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Army Regulation 700-51, Army Data Management Program, 1973

## ABOUT THE AUTHOR

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# EW TRAINING USING RADAR ELECTROMAGNETIC ENVIRONMENT SIMULATION

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## ABSTRACT

This paper describes what is necessary in a simulator to achieve a high degree of operator competence in interpreting a radar display in a threat environment. The achieved level of operator competence is a function of the degree of realism and complexity created. The models used for the generation of the signatures of aircraft/missile/ship targets, chaff, sea clutter, rain and jammers, operating in a dynamically controlled environment, are described in detail. The hardware/software implementation and equipment installation, together with problems encountered during the simulator design are also discussed.

## INTRODUCTION

Today's electronic technology can provide a realistic, accurate, and extremely flexible simulation of the electromagnetic environment compatible with the most sophisticated 2D and 3D weapon control and surveillance radar systems. This ability, to create on command, a simulation of a dynamic multiple-target/threat environment, including clutter and weather effects, allows for the performance of radar operator training to a degree previously unachievable. Instant recognition of and response to multiple threats is crucial to mission success - and often to crew survival.

The key lies in the ability to simulate radar returns and jammer signatures with a degree of realism not differentiable from real world radar inputs. The equipment must provide in real time that portion of an electromagnetic environment comprised of multiple airborne targets, multiple chaff events dispensed by the simulated targets, clutter, weather, and ECM waveforms emanating from selected simulated targets. The ECM waveforms should be capable of both denial and confusion techniques. In addition, the simulator must be coordinated with the real time operation of the radar with respect to radar pointing direction, range sweep timing, and transmitted frequency and phase. This modeling, therefore, should include accurate simulation of:

1. Signal strength variation due to target radar cross section (RCS) fluctuation.

2. Slant range and radar transmitter power.

3. Modulation due to target position in the antenna pattern (main, side, and back lobes.)

4. Doppler shift and doppler noise.

## THE TECHNICAL PROBLEM

In order to create an illusion to the radar of actual radar returns it is important to consider the many signal parameters and radar interfaces. I would like to briefly describe these radar parameters and then dig a little deeper into the dimensions of these parameters:

Radar Cross Section

Scintillation Noise and Other Noise Components

Target Dynamics

Path Loss Factors

Doppler

Scan Modulation and Antenna Gain

Extended Targets (Chaff, Rain, Sea Clutter)

Jammers

Radar (2D & 3D) and Operator Interface

### Radar Cross Section (RCS)

The RCS model should be the result of a simple operation input of mean cross section over a range that considers all sizes of expected encountered targets.

### Scintillation Noise and Other Noise Components

The model should include phase/amplitude fluctuation in regard to target aspect angle, amplitude noise modulation to simulate target cross section fluctuation and doppler frequency noise modulation to simulate target doppler frequency noise fluctuation.

### Target Dynamics

The target model should be capable of simulating both maneuverable and fixed targets in three dimensions, (range, azimuth, and altitude.) The maneuverable targets should be capable of linear and circular motion and of having a rate of ascent or descent applied individually.

## Path Loss Factors

All losses, whether one way or two way, should be modeled such as; range loss, frequency loss, chaff and rain attenuation, over a dynamic range and resolution compatible with expected target and jammer conditions.

## Doppler

Target doppler frequency should be modeled dynamically in accordance with the flight path motion of each target.

## Scan Modulation and Antenna Gain

The absolute pointing direction of the antenna should be tracked in real time by the simulator. The antenna patterns should be used to provide coordinated amplitude modulation for all modeled signals with respect to the one way or two way antenna gain as required.

## Extended Targets (Chaff, Rain, Sea Clutter)

Coherent radar returns from a number of extended targets, such as chaff, rain, and sea clutter should be modeled. The model should consider the additive effects of many scatterers, air mass motion effects, screening effects, and altitude, and in addition, should provide for both amplitude noise modulation to simulate cross section fluctuations and doppler frequency effects including doppler noise.

## Jammers

The simulator should be capable of modeling a number of threats assignable to selected targets. Denial techniques such as barrage and spot noise and swept CW should be available. In addition, noncoherent types of confusion techniques such as range deception with a cover pulse, inverse gain, synchronous and non-synchronous pulse train should be available. The coherent type confusion techniques should be range deception and inverse gain.

## Radar Interface

The simulator model should be compatible with both 2D and 3D radars and a direct summation with the real world radar input.

## Operator Interface

A simple operator interface is of paramount importance. Automatic and manual data entry should both be considered. In addition, a means of displaying continuously updated data on all targets should be considered.

# A RADAR ELECTROMAGNETIC ENVIRONMENT MODEL

## Radar Cross Section

Two distinct types of targets are considered, those that are short compared to a radar's pulse length and those that are long.

A target that is physically short effectively echos a near exact replica of the transmitted signal. Targets that are long include rain, sea clutter, and the extended chaff drops. For long or extended targets, the radar return is no longer a simple replica of the transmitted signal, but a superposition of many, many returns from individual scattering centers. Extended target returns are discussed later in this report. The RCS assigned to each type of target is based on experimental derived means. For example, aircraft typically vary anywhere from 0.1 to 20 square meters. This statistical mean is taken as a point of departure for all subsequent variation and is the operator entry into the system.

## Scintillation Noise and Other Noise Components

The signal returned to the radar's antenna for any given target, even if physically very short is known to vary from reply to reply. To achieve a realistic model, the more significant contributions must be considered.

The first important signal strength variation is the deviation from mean RCS due to irregularities of the target itself. Fig. 1 is a typical size aircraft. As can be seen, minor changes in aspect angle can vary reply signal strength up to 20 dB, yet for all of its wild variations, the return signal strength is essentially free of step functions.

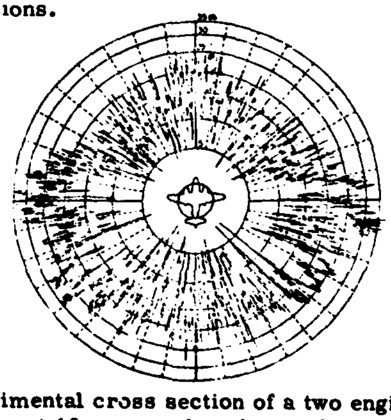


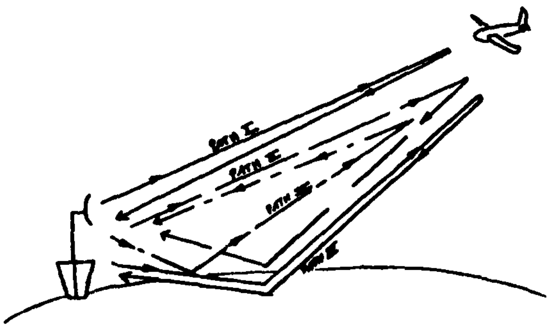
Fig. 1

Experimental cross section of a two engine bomber at 10 cm wavelength as a function of azimuth angle. (SKOLNIK)

When considering return signal strength variations on a pulse to pulse basis (PRI of 2 milliseconds) for an aircraft in a "g" limited maneuver the variations are quite minor. On the other hand, in the scan to scan period (perhaps 5 to 10 seconds) the return strength could vary 40 dB. We thus experience a high degree of correlation, pulse to pulse, and full decorrelation of signal strength scan to scan. The statistical behavior of the decorrelation is well defined in literature as Swerling Case I

$$P(\sigma) = \frac{1}{\sigma \text{ ave.}} \exp\left(\frac{-\sigma}{\sigma \text{ ave.}}\right)$$

The second most important signal strength variation arises from multipath. Figure 2 indicates the four possible multipaths considered on both transmit and receive.



Multipath Signal Lines
Figure 2

Depending on the geometry of the situation, the major variables being target range and elevation, the difference in path length can change radically with changes in aircraft position. As the radar wavelength for L and S boards are but 30 and 10 cm respectively, the aircraft motion, even under the modifying condition of the situation geometry, results in significant variation of differential path length on a pulse to pulse basis.

Path one, the most direct one, has the least attenuation. Path two and three experience attenuation from a single reflection but are both of the same length. Path four, the longest of them all, experiences twice the bounce loss of two and three. The most significant signal is thus path one, of nearly equal significants the combination of two and three, and with a much lesser effect from path four.

In the model used, path one has been assigned near equal significance with the combination of two and three.

This near equivalence of path one and the sum of two and three, were amply demonstrated by the naval tracking/tests run at Chesapeake Bay Annex during tracking experiments for low flying aircraft.

As signals in space add on a voltage basis, and as the two significant signals can be at any phase with equal probability, the addition can vary from the norm of unity (say 1 volt) for the direct ray (path one) to a maximum of 2 Volts and a minimum of 0 Volts. Expressed in dB we expect a variation from 0 to +6 dB upward to -infinity downward. The contribution from path four, however, prevents the zero (- infinity dB) and -20 dB is a realistic approximation.

The overall effect of this multipath problem is the rapid fluctuation of signal strength on a pulse to pulse basis, with but little variation of the mean on a scan to scan basis.

Again, the statistics of this problem are well described in literature, using the same equation as above, but classified as Swerling II.

The discussion above gave a basis for extent of the distributions used based on physical behavior. The slow variations can yield nulls down to -40 dB on occasion while the fast one generally are best described by a distribution between the limits of +6 and -20dB.

In literature Swerling I & II are often used as two distinct effects, some occuring at some time under some circumstances, and the other under some other conditions. Data recordings taken in the past on the AN/FPS 35, AN/TPS34, and others have convinced us that a real life situation involves both effects, i.e. superposition of both a Swerling I and a Swerling II case.

The fast variations, with a range of +6 to -20 dB (based on a quasi correlated statistically normal distribution in voltage, not power,) are combined with the slow near random variations, with prescribed distribution in the range from 0 to -40 dB. Special provisions were made to insure that correlating data is correlated for replies from any one target, yet be decorrelated from another target, though within the same radar beam.

Since the variations of correlating data are time dependent, the degree of change is based on elapsed time only and the radar PRI does not enter the generation of correlated noise.

## Target Dynamics

In order to create a dynamic scenario of multiple target/threat events a number of entered parameters must be acted on:

Target Number - Aircraft Identifier
Initial Position - Range, Azimuth, Altitude
Radar Cross Section - Mean Cross Section in Meters$^2$
Target Dynamics - Heading, Velocity, Turn Rate (Right or Left), Elevation Rate (Ascent or Descent)
Designated Jammer - COHO/NCOHO Type,

ERP, Pulse Characteristics, Target Number
Designated Chaff Dispenser - Type, Mean Cross Section, Extent, Target Number

To properly output the target data into the receiver front end, time and phase coherent with all radar system aspects, requires a number of events to take place. The target model must make the following determinations each radar PRI, properly synchronized with the transmitted signal and the radar antenna pointing direction, considering both aspects of azimuth and elevation:

Automatically Acquire Mode and Pulse Characteristics

Obtain Frequency Data

Obtain Transmitter Peak Power Out Data

Pulse Time Delay Relative to Inputted Target Range

Azimuth Position Synchronous with Antenna Azimuth Angle

Altitude Position Synchronous with Antenna Elevation Angle

Antenna Platform Data Ship Parameter Correlated

Calculate Doppler Offset Frequency as a Function of Slant Range Rate

Calculate Target Power as a Function of Target RCS and Radar Peak Power

Calculate Antenna Gain as a Function of Target Position and Antenna Pointing Angle

Calculate one way or two way as a Function of Range.

Input Frequency Loss Word

Determine Chaff or Rain Attenuation if applicable.

Output Target Pulse in Real Time Synchronism at the Proper Power Level and Frequency.

The above model parameters are applicable to each target inputted into a scenario. As the number of targets and/or events increase, additional determinations enter the generated model.

The multiple targets must be properly range ordered and azimuth and elevation gated in synchronism with the radar. Each PRI all targets must be updated in range, azimuth, and elevation to be properly outputted into the radar receiver.

Since these will always be some restriction on the allowed number of rf channels, some degree of shadowing will probably be necessary.

Path Loss Factors

The Radar Range equation readily calculates the signal strength a Radar receiver would see given some of the basic parameters of the radar's operation (frequency, power) and the location (range) of the target.

$$R^4 = \frac{Po \times G^2 \times \sigma \times e^{-2aR}}{(4\pi)^3 \times \lambda^2 \times P_r \times L}$$

The Radar Range equation in the form shown above makes a number of assumtions a) that the $\sigma$ (RCS) is fixed, b) that there is but one path between the Radar and the target and c) the attenuation and losses reamin invariant. In a real life situation this however, is not so and the simulation must take into account these variations to present a realistic picture.

The RCS variations have been previously discussed together with the multipath considerations between radar and target. Added to the model are two other attenuator factors in addition to the range loss considerations, such as; frequency losses and target attenuations due to chaff or rain.

Doppler

All moving targets generate a doppler offset frequency relative to their slant range rate, except for those moving in a concentric circle about the radar. These targets are not only the maneuverable targets inputted into the simulator, but also the extended targets such as chaff, rain, and sea clutter.

The doppler effect causes the signal reflected by a moving target to be offset in frequency by an amount $f_D = \frac{2V}{\lambda}$

where $f_D$ = Doppler offset frequency (Hz)
V = Relative velocity (Slant Range Rate) between radar and target (m/su)
$\lambda$ = Wavelength of currier frequency (m)

In order to properly output each moving target pulse, phase coherent with the radar, the proper doppler offset frequency must be modeled. This will require two simulator calculations. One, to determine the instantaneous slant range rate as a function of the inputted velocity and heading, and second, calculating the doppler offset frequency or phase. These calculations are obviously only performed on those targets entering the radar antenna main beam or side lobes.

An understanding of how a radar processes the incoming signals to differentiate between non-moving clutter and moving targets helped to arrive at the solution implemented.

On a short pulse basis common to most radar system, it is an impossibility to determine the phase change, as a result of doppler offset,on a single pulse basis. However, an examination of successive PRI's shows that echos from fixed targets remain constant throughout, but echos from moving targets vary in amplitude from sweep to sweep at a rate corresponding to the doppler frequency.

Figure 3 illustrates this phenomena. (Taken from Skolnik "Introduction to Radar System")

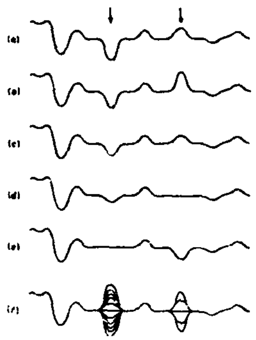



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Fig. (a–e) Successive sweeps on an MTI radar A-scope display (echo amplitude as a function of time); (f) superposition of many sweeps, arrows indicate position of moving targets.

By measuring or detecting this phase change on successive PRI's a determination can be made of the presence of moving targets. A radar's capability to do this on a 2 pulse, 3 pulse, or 4 pulse basis, gives an indication of the degree of MTI available.

Two different models can be used in the simulation of doppler. Precision offset oscillators yield excellent duplication of doppler with but minor sidelobes. Since however, one oscillator must be dedicated to one speed, the range of speed that can be simulated are limited. An alternate approach is the use of phaseshifters, with some digital networks dedicated to each target in view. Since the phase is constant during each transmission period, the sidelobe level is not quite as good as the individual oscillator, but this approach can readily handle a multitude of speeds and targets. Typically a 4 bit phaseshifter in an L band system yields a duplicable speed resolution of about $\pm$ 10 knots for a simulated target speed from $\bar{0}$ to $\pm$ 2,800 knots, i.e. $\pm$ 1/4%.

The doppler for extended targets, which for this simulation are considered stationary in range and azimuth, is a doppler distribution of the individual scatterers symmetrical about zero. By a correct choice of AM noise modulation bandwidth, the sought for doppler spread (symmetrical about zero) is duplicated by the AM sidebands of the AM modulating signals. The rise and fall times of the generated AM noise signals previously discussed, can be controlled to yield the spectral spread and thus the range of the simulated doppler spread.

Scan Modulation and Antenna Gain

To continue on the approach of creating as realistic a model possible, actual antenna pattern data experimentally obtained can be utilized to amplitude modulated the simulated targets. The model created considers the effect of gain, side lobe structure, and half power beamwidth. The approach considered is to store the values of antenna gain relative to peak in ROM with sufficient capacity dependent upon the desired resolution and system accuracy. The ROM address locations are then determined by the angle away from boresight. By this technique there is no restriction on antenna pattern symmetry. The only restriction is based on storage capacity and the bits allocated for ROM addressing. For the usual target return loss the antenna gain is used both in the transmit link and the receive link. For the jammer case, it is only needed for the receive calculation.

Extended Targets (Chaff, Rain, Sea Clutter)

Extended targets create an echo return that is no longer a simple replica of the transmitted signal; but a superposition of many returns from individual scattering centers.

Extended, or long targets require somewhat different techniques to simulate. For one, these targets do present a shape of their own which has to be superimposed with the radars own parameters.

In range, the convolution is that of the radar pulse, a square wave, with that of the extended target shape, such as rain or chaff. In azimuth the Antenna beam shape, as it sweeps across the target, must be imposed upon the azmuthal variations of the target.

To generate the basic data, a convolution integral of the type below was used to generate the basic data known as RCS for the short targets.

$$RCS(\theta) = \int OBJ(\theta) * ANT(T-\theta)\, dT$$

For Chaff, the variations are two fold. The vertical variations with time can best be described as a normal distribution with the upper 2-sigma anchored at the level of sowing and a mean fall rate dependent on the material employed. Typically the centroid fall rate is about 250 ft/minute. Simultaneously the lateral spread, perpendicular to the direction of sow increases at about the same rate.

Rain, though similar to Chaff, in certain respects has some significant differences. For one, once rain has initiated, with its higher fall velocity, it can be taken as (a) reaching the ground in near zero time, and (b) that its vertical profile is uniform from the ground up to the level of the forming cloud.

Also, while Chaff has some kind of uniformity along the line of sow, Rain is a more central phenomenum. It contains a near circular center with a density taper toward the edges. Again, unlike Chaff, while the reflectivity decreases outward from the center, it does not taper to zero but experiences a step function near its edges providing a definite profile.

Further, in the discussion of Doppler, while the individual Chaff particles have a motion like a falling leaf, (i.e. significant oscillatory motion in the horizontal compared to the vertical drop), the majority of the rain motion is vertical, and any lateral motion due to wind is uniform to all rain drops. The last statement holds for the rain below the cloud, which is the majority of the rain field in Radar view, though not within the storm center of the raincloud. As the latter subtends but a small vertical angle, it can be neglected for search radar simulation.

In the discussion of the small targets, the multipath problem was considered (i.e. the superposition of two different signals (Path I and Path II and III.)) In the case of large extended targets a similar effect takes place, however, with many many more reflectors delivering their one reply at slightly different times and phases.

In the small targets, the effect was variation of the signal, as simulated, of various amplitudes. A finer resolution would not do as the Radar receiver bandwidth is matched to the transmitted signal duration. For extended targets, however, much longer than a radar pulse width, the receiver can resolve such variations though bandlimited to the signal bandwidth. Thus, the random variations again in the range of +6 to -20 dB, are superimposed on the return signal. A noise pattern is used with the data varied in a broad band manner up to frequencies compatible with the transmitted pulse length, i.e. Receiver bandwidth.

This high frequency noise (500 KHz for a 2 microsecond Radar) is then superimposed in the amplitude patterns representing the convolution of the target physical reflectivity profile and the scanning antenna pattern.

For straight pulse Radars, the Chaff/Rain signal control is complete at this point. For Chirp systems one factor has to be considered, in that scatterers at different ranges reply with different frequencies at the same time. For small targets a replication of the FM pulse suffices. For extended targets an additional high rate FM modulation is required to simulate the receipt of multiple frequencies at the same time.

For the simulation of extended targets, the modulating wave shape is modified to simulate the frequency centroid as a function of time during the return signals duration (Pulse width, plus target depth.) That new centroid waveshape is further modulated with a high frequency signal (higher than the receiver bandwidth), whose peak to peak excursions correspond to the earliest and latest frequency in view at any given instant.

The Sea return signal uses similar techniques. It differs from either the Chaff or the Rain (longitudical or cylindical symetry) in its density pattern.

While Rain or Chaff are isolated events, Sea Clutter differs in that (a) it is a 360 degree event, (b) it appears only at close in ranges, less than the 15 NM ships Radar horizon and (c) in that the main reflecting elements are not the surface of the ocean and its waves, which could be subject to separate analytical treatment, but from all indications are from the spray patterns located above the wave.

The main reflecting spray patterns are known to be correlated to the wind direction (not wave direction) and appear as slowly moving reflecting strips perpendicular to the wind direction. Additionally, minor small targets appear to fill in the spaces between the main scatterers, though of less scattering crossection.

There is one more wind caused effect, in that the mean reflections are maximum into the wind, somewhat less alee, with an even further reduction cross wind yielding an hourglass figure for the clutter simulation.

The complexity in forming a sea state pattern is in the generation of the cross wind lines and minor scatterers as a function of wind direction; which in general, correlate on a scan to scan basis but drift in general position as a function of minutes. The simulation of the multiscatter effects are handled similar to other extended targets.

A special problem to be handled for Sea state is its close proximity to the Radar. The effect of $R^4$ on extended targets is minor. E.g. a 3 mile rain at 25 miles has but minor signal variations due to range, effectively by the 26 dB noise modulation. Sea returns at the range from 1 to 15 NM, however, have major contributions from the $R^4$ law that must be incorporated into the model.

## Jammers

To complete the electromagnetic environment, model, consideration must be given to expected threats. As a result provision has been made to include simultaneous coherent and noncoherent radiation from collocated jammers.

The replication of these jammer platforms is accomplished with independent ERP control and various operation modes. Among these are coherent range deceptions (including cover pulse) and inverse gain, noncoherent swept CW, spot and barrage noise, plus synchronous, and nonsynchronous pulses.

### Radar Interface

In order to achieve the degree of coherency necessary, certain information is required from the radar. The STALO and COHO frequencies are necessary to recreate a return echo with the necessary degree of phase coherency. A main bang trigger to synchronize the system and antenna scan and platform information are also necessary. Figure 4 indicates the major interfaces.

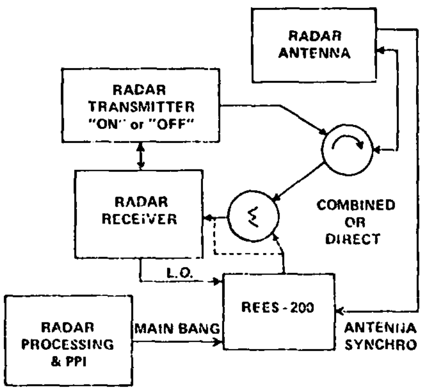


Figure 4
REES CONCEPT

### Operator Interface

To simplify use of the system, a microprocessor controlled video display terminal was selected out of the many considered. Data may be entered by means of the keyboard, RS-232 serial or IEEE STD 475 parallel data link inputs. The operator provides the simulator with information relating to the aircraft and the radar. This information includes the aircraft identification, signature, and motion dynamics. Also entered are the radar parameters including frequency, amplitude, and time dimensions.

The parameters defining the nature of the chaff and the type of jamming is entered for each aircraft that carries these countermeasure capabilities.

The data that has been entered for the aircraft, radar, chaff and jammer is presented on the display. As the data changes, the display changes. There is a constant updating of the aircraft position to show its new range and bearing at any time during the mission. Automatic self test and a predetermined scenario may be initiated at any time by operator or data link intervention.

## MODEL IMPLEMENTATION

### Hardware Implementation/Radar Interconnect/Control

A simulator incorporating many of the features discussed in the previous section was designed, fabricated, tested and delivered. It was designated as a Multiple Threat Generator (MTG-100) and was integrated at the Signal Processing Laboratory Radar at Rome Air Development Center (RADC). Its performance characteristics are included at the end of this section.

Figure 5 shows the simulator and its radar interconnections and Figure 6 is a simplified block diagram of the simulator with its interconnections. A more detailed block diagram depicting a single channel of the MTG-100 is shown in Figure 7. One such channel is available for each R. F. band the simulator is to be operated in.

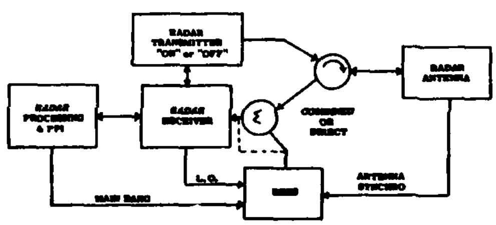


Figure 5

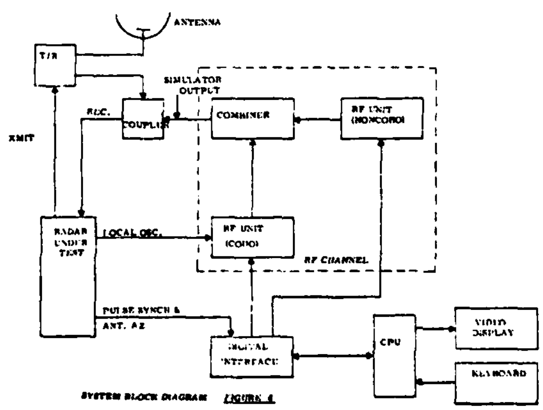


Figure 6

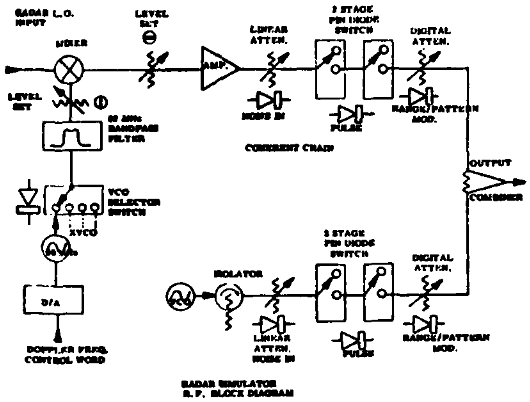


Figure 7

Each channel consists of two chains, a coherent and a noncoherent chain. The input frequency of the coherent chain is determined by a signal derived from the radar local oscillator.

In the system chosen as illustration, the radar transmitted frequency is 80 MHz above the local oscillator input. The 80 MHz oscillators are crystal controlled VCO's, one dedicated for each target, allowing Doppler shift simulation to be achieved by offsetting the XVCO's.

The mixed product is amplified to compensate for mixer conversion loss and component insertion losses.

A series of control elements (i.e., linear attenuator, R.F. switch, digital attenuator) are used to control the amplitude of the R.F. signal. The 30 dB linear attenuator superimposes the noise modulation generated by digital noise circuits.

The R.F. switches are used to pulse modulate the signal (with pulse widths as narrow as 100 nanoseconds to full CW) with an on-off ratio of 120 dB.

The actual control of the R.F. circuitry is the responsibility of the digital interface circuitry under the control of a microprocessor. The microprocessor performs the calculations for the proper attenuator word, computes the range delay, and sets the pulse width. In addition, there is circuitry for azimuth gating based on radar antenna position and beam width.

The digital attenuator (.1dB steps to 120 dB) is driven by the CPU and digital interface circuitry to provide the range, antenna pattern loss and other dynamic and static losses.

Both the coherent and noncoherent signals are combined at the output and are available at a single output port.

The R.F. coherent signal is combined with a signal generated by a voltage controlled phase lock loop oscillator whose output frequency is digitally selected. This second oscillator is the R.F. source for the noncoherent chain which provides simultaneous jammer signal capability.

The digital circuitry, Figure 8, consists of three main elements: a video terminal, the central processing unit, and the interface hardware circuitry. The video terminal is essentially the front panel of the radar simulator. This terminal may be used to enter all data, control commands and make scenario decisions. The operator obtains current status and other housekeeping information from the display.

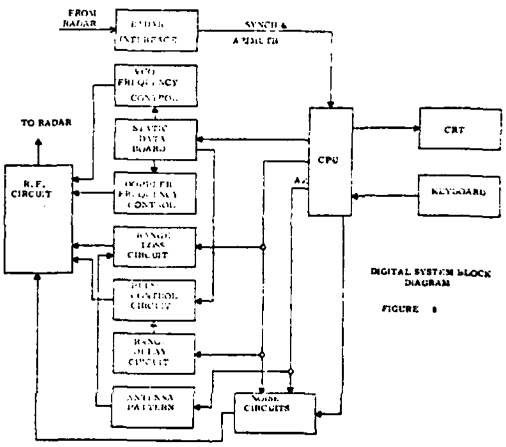


Figure 8

## Software Implementation

Both dynamic real time and static processing is achieved with the assistance of two 8080 microprocessors with both independent RAM and common memory. The microprocessors perform the radar power and cross section calculations, as well as range ordering and bearing positioning. The computers also provide the routing of data in and out of the video terminal for both display and operator interactivity.

Updating of the scenario and formatting of video data is performed by the CPU's. The mainline program is stored in less than 8K of PROM. The CPU's perform a range ordering task and provide a "shadowing" signal whenever two targets are within 10µs of each other. The range ordering, which at present is a modified "bubble sort," arranges the aircraft in the order of radar response at their computed ranges. This order, which is strictly range dependent, is then gated with the antenna azimuthal information. Each time the azimuth gate (representing the antenna beam painting of a particular angular sector) repeats a particular sector, the order of the range of targets could possibly be different. A comparison is made between each target, its radial range component is considered, and all of the targets are repositioned.

The data transmitted to the interface hardware consists of static data, computed once each time data is entered from the terminal, and dynamic data, computed during the scenario update about once each 5 millisecond interval. Range and range related phenomena is computed on a 50 foot resolution interval and Doppler frequency from 0 to ± 2100 knots in 1 knot increments.

In order not to disturb the simulation when new data is available from the CPU's, two data registers (Readout Files) are used in the interface hardware. Data is read in and changed in one, while read out on the other file. By this "ping-pong" approach, a smooth update is maintained and synchronization between the radar main bang and the CPU clock is not needed.

## Noise Modeling

In order to create as realistic a target simulation as possible, the noise characteristics shown in Table 1 were included in the noise generation circuitry for aircraft and chaff targets.

TABLE 1 NOISE MODEL

| | | | |
|---|---|---|---|
| **AIRCRAFT** | | | |
| EACH AIRCRAFT: FULLY INDEPENDENT OF OTHER AIRCRAFT | | | |
| | AMPLITUDE (dB) - SUM OF: | | |
| "A" "GLINT" | NOISE: CORRELATED CHI-SQUARE TIME/FREQUENCY DEPEND TARGET NUMBER CORR | RANGE: 0 - -[illegible]dB MEAN: -[illegible]dB | STEP RATE: 1 - [illegible]KHz DECORR TIME: [illegible] MSEC |
| "B" "FADE" | MODULATION: CYCLIC EMPIRICAL TIME (ONLY) DEPENDENT TARGET NUMBER CORR. | RANGE: 0 - -[illegible]dB MEAN: -[illegible]dB | CYCLE TIME: 1 per [illegible]-10 SEC |
| | TOTAL RANGE LIMITED TO: | 0 - 30 dB | |
| **CHAFF** | | | |
| ALL CHAFF MODULATION TREATED AS SINGLE MODEL | | | |
| | AMPLITUDE (dB) - SUM OF: | | |
| "C" "CHAFF" | CORRELATED-GAUSSIAN ANTENNA POSITION DEPEND | RANGE: 0 - -[illegible]dB MEAN: -1.[illegible]dB | BEAM WIDTH CORRELATION |
| "D" "TIME" | UNCORRELATED-GAUSSIAN TIME/FREQUENCY DEPEND | RANGE: 0 - -[illegible]dB MEAN: -2.[illegible]dB | DECORRELATION: [illegible]KHz |
| | TOTAL RANGE LIMITED TO: | 0 - 10dB | |

A) Each aircraft's noise components are fully independent of other aircraft.

B) The glint component is chi-square distributed, time correlated, target number correlated, and frequency dependent.

C) The fade component is an empirical cyclic time only related function which is also target correlated.

For the chaff noise modulation implementation:

A) A Gaussian distributed, antenna position related, random walk pattern was used, plus -

B) A Gaussian distributed time and frequency dependent noise distribution.

The noise seen by a radar when receiving a skin return is comprised of several elements which are both time dependent and target dependent. One element of noise is a result of temporal displacement (GLINT).

There is another element that is spatial contribution which is related to antenna position, target cross section and target orientation. A further distinction has to be made between noise from aircraft returns and that from chaff returns.

For a single aircraft the amplitude modulation, whose probability density function is a chi-square distribution, decorrelates both with time (pulse to pulse) and frequency. It also provides scan to scan independence. This component of noise represents the GLINT portion of the noise modulation.

The second element of the noise modulation is the contribution due to target fading. This fade pattern is a slow change in target return amplitude due to aspect angle changes This spatial component was instrumented using a cosine$^4$ function with a variation in the period as a function of the target. The "Fade" component, therefore, was empirically derived and assures different noise behavior for different targets.

The amplitude range of the total aircraft noise is limited to 30 dB with the mean at 6dB. The chaff noise modulation has a 10 dB variation (±5 dB) with a mean also of 6 dB. This assures that the mean return power is the same for identical cross sectional areas.

In the case of chaff, a time invariant antenna position component must be generated. This models the expected variation in noise as the antenna sweeps different portions of the chaff. The noise will be highly correlated for angular changes which are small compared to the half power beamwidth of the antenna and completely decorrelated when the antenna moves greater than the half power beamwidth.

Figure 10 is a block diagram of the noise generator for the coherent channel.

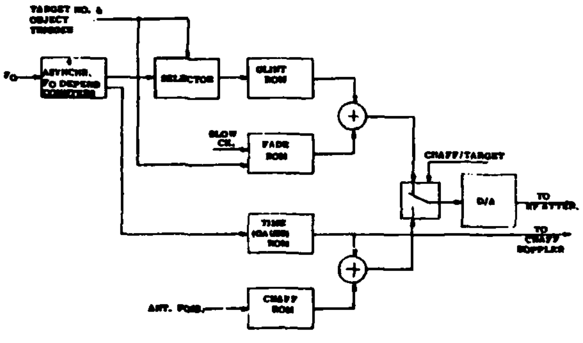


Figure 10

Four counter outputs, whose clock rate is frequency dependent based on radar operating frequency, are added and multiplexed to provide up to ten different clocking rates. The multiplexed outputs are used to address the "Glint" ROM. Each aircraft will then have an associated "sample" rate based on radar frequency and pulse repetition rate and its aircraft target number.

A separate slow clock is used to provide the seven least significant bits of the "Fade" ROM address. The aircraft number is used to provide the three most significant address bits. In this way, each aircraft has its own unique "fade" pattern.

The sum of the two ROM outputs is then selected by a multiplexer (decision based on aircraft or chaff event) and fed to a digital to analog (D/A) converter. This analog voltage is used to drive a linear attenuator which modulates the R. F. signal.

The chaff noise generation technique is similar except that the ROM addresses are generated by both a time frequency derived clock and the antenna position obtained from the synchro data. This combination models the variation due to chaff motion (time) and decorrelation due to frequency. It also accounts for the non-homogenous distribution of chaff particles for a given chaff event.

## Noise Jammer

While the coherent noise distribution is determined by the data stored in the various ROM's dedicated for this task, it is also necessary to generate noise to be used as modulation for on-board jammers. (The airplane is the jammer platform.) This is done in an analog circuit using a noise diode and amplifier as source voltage for a linear attenuator. This modulator affects the noncoherent signal (representing jammers) only. For broad band (barrage) noise, it was necessary to use a somewhat different approach than amplitude modulation. The linear modulator's modulation bandwidth is only about 300 KHz. Barrage noise should produce a spectral bandwidth in excess of 20 MHz. To accomplish this, the same noise diode source is used, amplified, and superimposed on the error voltage of the VCO. The phase lock circuit cannot respond fast enough to correct this noise voltage and the result is a noise modulated FM signal. This signal occupies a bandwidth of better than 20 MHz and spectrally simulates a barrage jammer.

## Antenna Pattern Generation

The MTG-100 system is capable of modeling the effect of gain, side lobe structure, and half power beamwidth of an actual or ideal antenna pattern. The values of antenna gain relative to the peak are stored in 1024 locations where the address location is determined by the angle away from boresight. There is no restriction on the antenna pattern symmetry. The only restriction is based on the storage capacity and the bits allocated for ROM addressing. Generally, a 60 to 70 dB dynamic range may be programmed with resolution steps of .1 dB.

For the usual radar target return loss, the antenna gain is used both in the transmit link and the receive link. For the jammer case, it is only needed for the receive calculation. Therefore, only the "one way" gain of the antenna is stored in the ROM's and the interface circuitry doubles the gain in the "two way" case.

If, as an example, we store about $\pm 11^{\circ}$ of an antenna pattern, then we can store values every $.022^{\circ}$ of the pattern. This should be adequate even for the highest gain antenna in use today.

## Doppler

Of the many ways to implement a Doppler shift (i.e., Serrodyne, single sideband generator, etc.), only one method can produce the pulse to pulse phase coherency needed along with low unwanted spurious signals; that is, using a separate XVCO per target. Refer to Table 2.

Regardless of the Doppler processing techniques of the radar under test, the Doppler shift associated with a particular target must maintain its offset frequency and phase continuity. Because the radar only sees the target for a small portion of the Doppler cycle, it must take several samples and reconstruct the Doppler shift. Therefore, even though the radar is not looking at the target, the Doppler phase must not contain discontinuities or else an error will be introduced during the next sample (pulse) period. In addition, unwanted sidebands and carrier leak-through, if excessive, can produce errors during processing.

At present, the Serrodyne method or the single sideband method at best would produce spurious frequencies and carrier leak-through that would be between 20 and 35 dB below the carrier. To assure that spurious outputs are 50 to 55 dB below the desired output, a separate oscillator was used for each target. Each of the oscillators are continuously operating and are assigned to individual targets. The outputs are selected under CPU control when that target is to appear. The selector switch presents a load to the oscillator at all times, thereby eliminating possible pulling during switching. The oscillators (crystal controlled VCO's) are capable of being offset up to ± 30 KHz as a function of a DC control voltage.

The CPU was used to calculate the Doppler shift needed based on operator inputs of velocity and radar frequency used. The calculated Doppler shift word was applied to a digital to analog converter whose reference voltage provided the scaling factor to convert the frequency word to a correct shift of the XVCO frequency.

The simulation of chaff Doppler presents a different challenge. The chaff cloud requires a random shift correlated with time and operating frequency. The signal produced for amplitude modulation of the chaff noise has a component which is related to both time and frequency. By using this component before it is combined with the spatial noise component, the chaff Doppler was derived both as a function of operating frequency and time. The four least significant bits of the chaff noise ROM were used as the control word for the XVCO digital to analog converter. This simulates the effect of wind shear, dipole tumbling, turbulence, and falling of the chaff cloud.

TABLE 2 DOPPLER FREQUENCY SIMULATION

REQUIREMENT: 6 TARGETS PLUS CHAFF

TARGET VELOCITY FROM -2100 to +2100 KNOTS
CHAFF VELOCITY FROM -24 to +24 KNOTS
SPURIOUS PLUS FUNDAMENTAL LEAKAGE 60 DB DOWN
PHASE COHERENCE: --- EACH TARGET---
--- PULSE TO PULSE---
---ANT BEAM TO ANT BEAM---
RADAR RESOLUTION---PHASE DEPENDENT---8 KNOTS

APPROACHES CONSIDERED:

PHASE SHIFT---DIGITAL/ANALOG---FUNDAMENTAL/IF
SINGLE SIDE BAND MODULATION (SSB)
MULTIPLE VOLTAGE CONTROLLED CRYSTAL OSCILLATORS (VCXO)

SELECTED APPROACH:

MULTIPLE VCXO
ADVANTAGES: INHERENT MEMORY
DESIRED STABILITY
SPURIOUS REJECTION
DESIRED LINEARITY

IMPLEMENTATION:

TARGET RESOLUTION: 104 Hz 8.2 KNOTS
CHAFF RESOLUTION: ≦15 Hz 1.2 KNOTS

PERFORMANCE SPECIFICATIONS

| | Baseline | Options |
|---|---|---|
| Frequency: | 1250-1350 MHz<br>2900-3700 MHz<br>(1 MHz steps) | 0.5 to 18 GHz |
| Output Power: | Coherent Channel: -6dBm<br>Noncoherent Channel: 0dBm | |
| Dynamic Range: | >100 dB (0.1 dB steps) | |
| Doppler Simulation: | 0 to ±2100 knots | |
| Target Capability: | 6 Aircraft, 9 Chaff Events (Point, Medium, Large) | 127 Aircraft plus Chaff Events |
| Chaff Motion & Effects: | Stationary | Air Mass Motion, Screening, Altitude |
| Environmental Anomalies: | | Clouds, Snow, Rain, etc. |
| Target RCS Range: | 0.1 to 1000 meters$^2$ | |
| RCS Dynamic | Static Mean plus Scintillation | Dynamic Tracking |
| Target Pulse Width: | 0.3 to 50 microseconds | |
| Target Range: | 6 to 400 NM | |
| Target Azimuth: | 0 to 360° | |
| Azimuth Rate: | ± 6 degrees/second | |
| Radar/Jammer Power: | 0 to 100 dBw | |
| Jammer Simulation: | | |
| Number | 2 | Heavy Density Model |
| Type | Coherent & Noncoherent | |
| Modes | Range Deception (including Cover Pulse,) Inverse Gain, Synchronous & Nonsynchronous Pulses, Swept CW, Spot Noise, Barrage Noise | |
| Antenna Pattern Data: | Azimuth Coverage | Azimuth & Elevation |
| Complex Waveforms: | | Pseudo Random Binary Phase Coding 200 Megabit Clock Rate |
| Identification: | | IFF SIF, Mode 4, (SLS) |

## Equipment Installation

The equipment was successfully installed at RADC with the radar interface accomplished via a 20 dB directional coupler to minimize any degradation of radar receiver sensitivity. Test data was obtained and the MTG-100 met the performance characteristics specified in the contractual statement of work.

## Problems Encountered

One of the major problems encountered during the design phase of the MTG-100 was in the generation of the doppler offset frequencies. The initial design concept basically ignored the degree of phase coherency required to be dedicated to each moving target, PRI to PRI, and the phase memory that had to be dedicated to each target within the antenna beam. Coupled with the above was the requirement that carrier leak through be 60 dB below the doppler offset frequency. The initial concept utilized a phase locked VCO switched in frequency to generate each doppler offset frequency to be mixed with the incoming radar L.O. frequency. All the requirements could be met except for in beam and PRI to PRI phase coherency.

Two different methods can be used in the simulation of doppler as has been previously discussed in the Doppler model. Due to the 60 dB rejection criteria imposed on the MTG-100, the dedicated XVCO oscillator approach was used.

# RADAR OPERATOR/MAINTENANCE TECHNICIAN TRAINING

## System Performance Requirements and Environment Control

If a situation can exist, that requires judgment and operator skills to properly evaluate and respond to, that situation needs to be repeatably generated for proper training. If a judgment may be necessary dependent upon various shadings of displayed data, proper training can only be accomplished by either generating the actual conditions (flight/jammer trials) or by having available a realistic simulation.

Both of the above training aspects can be cost effectively realized by the use of a properly specified electromagnetic environment simulation. By properly specified, we mean an environment simulation virtually undifferentiable from the real world. Add to this a capability to generate a dynamic multiple-target/threat environment with chaff dispensing aircraft, sea clutter, and rain events, and the ability to sum these signals with real world inputs, all sorts of training scenarios become possible.

Not only training scenarios are possible; in addition, the simulation capability can be used to solve specific environment/mission problems. Here are a few examples:

1. Place a simulated target cross section within an actual displayed chaff corridor, vary its RCS and determine the size target that would be visibly displayed.

2. Do the above varying the simulated target's slant range rate to see if a target's velocity has a bearing on detectability.

3. Do "1" above to determine the size target that can be seen through a rain event.

4. A particular jammer ERP level can be determined for both "burn through" and display jamming.

5. Data can be extracted from unknown targets by generating simulated identical target tracks.

## Simulation Applicability to Training

The training will only be as good as the degree of realism available. If it looks like a simulated signal, a certain degree of training can be realized, but not the ultimate. If the operator cannot tell the difference, then the training is being accomplished under virtual actual conditions at a fraction of the cost.

# CONCLUSIONS

To achieve a high degre of operator competance in interpreting a radar display in a threat environment requires a high degree of signal realism. The target/signal models used in the simulator discussed were based actually upon data obtained, under a variety of conditions, using various radar systems. Today's electronic technology allows the generation of a simulated radar electromagnetic environment virtually undifferentiable from real world returns.

# ABOUT THE AUTHORS

Mr. John F. Michaels is Vice President of Marketing at Republic Electronics Incorporated. He is responsible for all marketing and new business activities within the company. Most recently his positions have been Director of New Business Development, and Director of Marketing respectively. His background includes engineering, program management, and marketing in the avionics field, including TACAN, IFF, and radar test and simulation system and he served as program manager on the Multiple Threat Generator (MTG-100) discussed herein.

Mr. Michaels holds a BSEE from Rugers University.

Mr. William W. Kestenbaum is a Senior Systems Engineer at Republic Electronics. He is responsible for the design of Radar Related Simulators. For the past 35 years, he has been a Systems Engineer, Program Manager, and Research Section Head in Radar and Navigation Systems.

While in the U.S. Navy, he both received training and taught Electronics Warfare Systems. He holds a B.M.E. from CCNY, an M.E.E. from NYU, and received further training from the Polytechnic Institute of New York, where he is a member of the Adjunct Staff.

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